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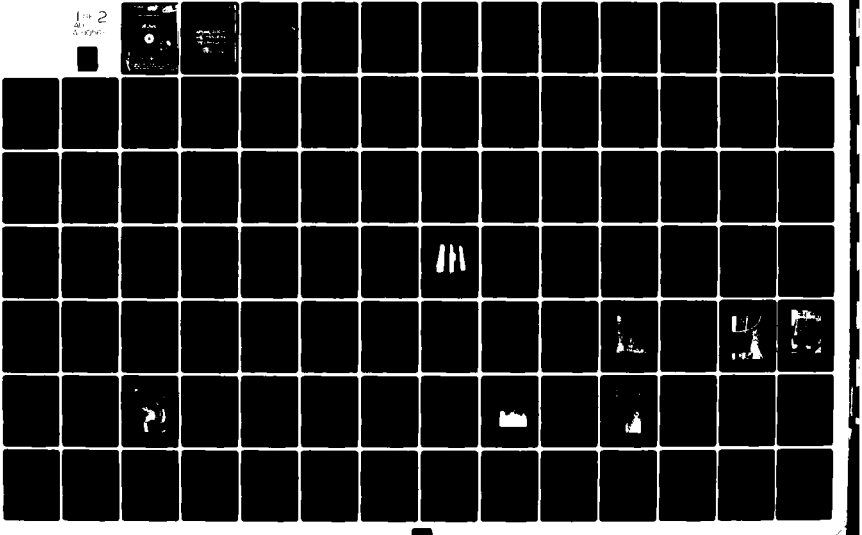

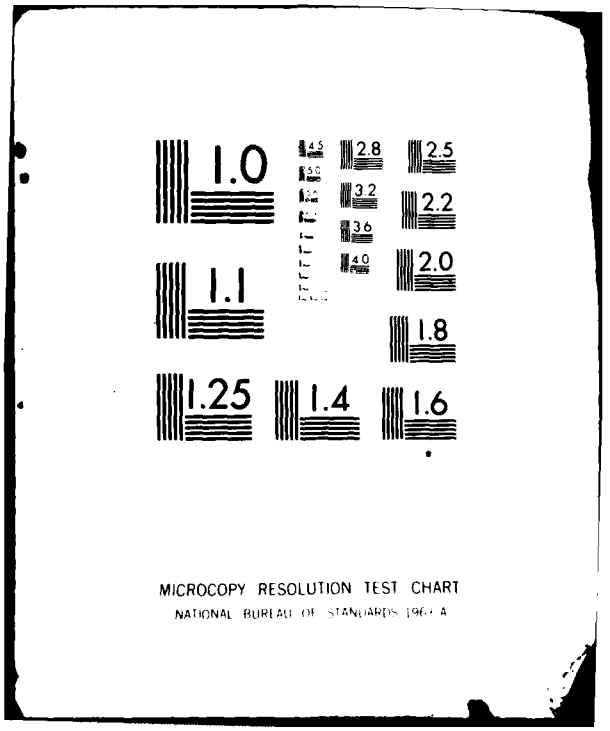
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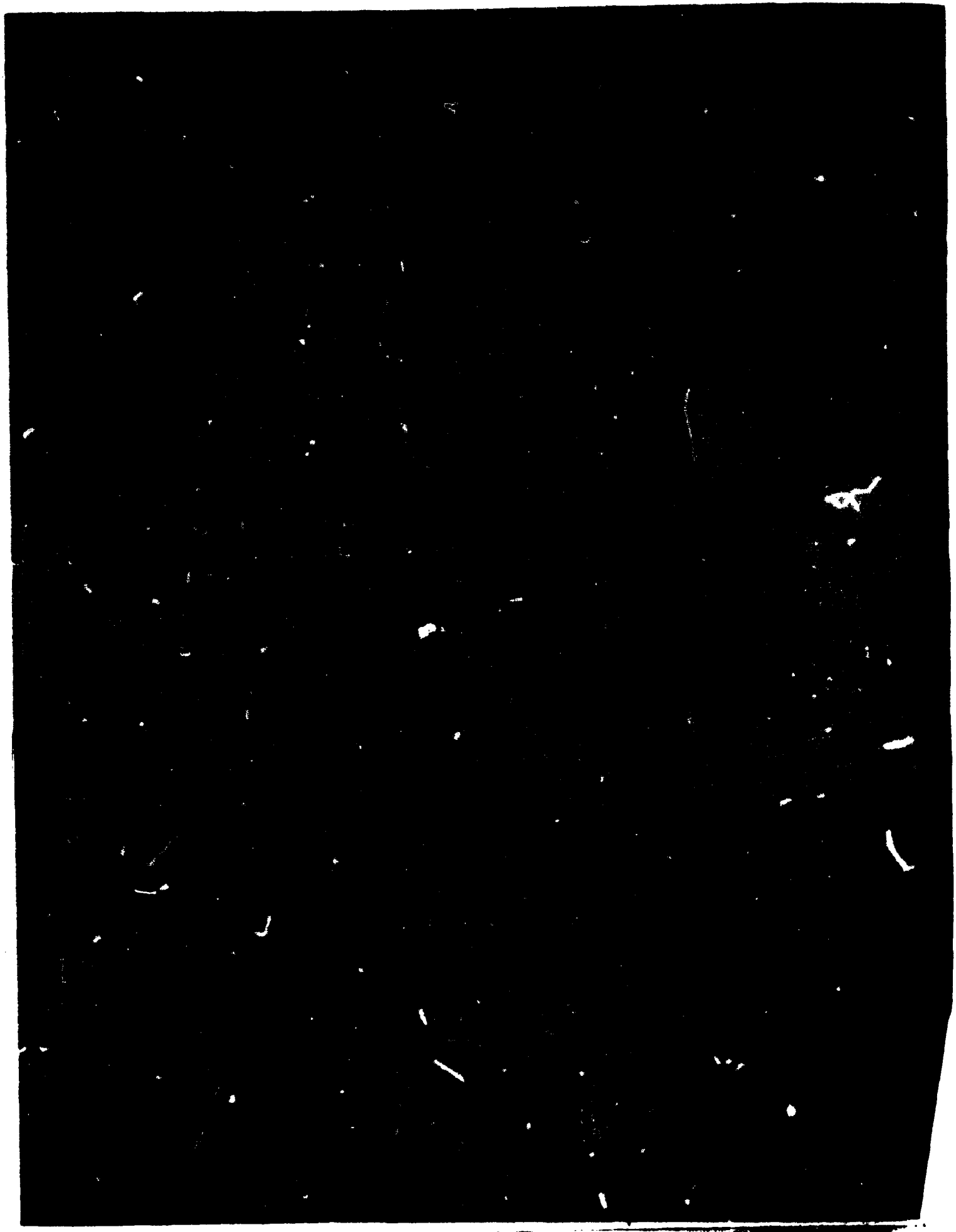

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16. Abstract

A generalized analytical model of the wind, current, and wave forces on an elliptical cylinder is presented with specific application to predicting the list angle of an articulated spar buoy. The major physical and environmental parameters present in the system are then analyzed to determine their relative influence on these forces and moments.

Data to validate this analytical model was obtained from both laboratory and field experiments. Model tests performed in a circulating water channel revealed that directional stability was a significant factor in determining the overall performance of elliptically cross-sectioned spars. Of the shapes investigated, only a circular cylinder with splitter plate was found to be stable and to return to an equilibrium position if displaced. Laboratory measurements of the circular cylinder list angle for various current velocities showed generally good agreement with that predicted by the analytical model.

Using a nominal 6 inch (16.83 cm) diameter, ins[illegible] aluminum spar 18 feet (5.49 m) in length with a splitter plate, field test[illegible] obtained over a broad range of current and water depth conditions. Data from thi[illegible]eld experiment also showed good agreement with that predicted by the analytical model.

On the basis of these results, it was concluded that for spars of circular cross-section, the analytical model is a good predictor of an articulated spar's behavior and, consequently, a useful design aid. Possible improvements to both the laboratory and field tests are suggested.

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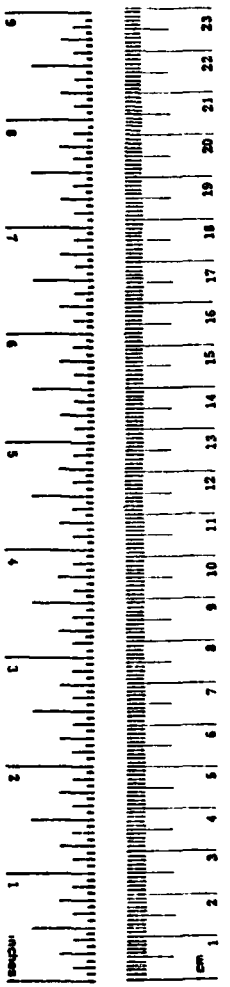
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

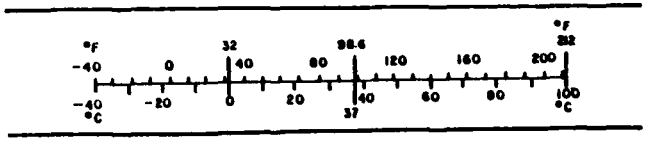
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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NOMENCLATURE

A	Major Axis Length of an Ellipse
A_c	Cross-sectional Area
A_p	Projected area
a	Wave Amplitude
B	Minor Axis Length of an Ellipse
C_D	Dimensionless Drag Coefficient
C_I	Dimensionless Inertia Coefficient
C_M	Hydrodynamic Mass Coefficient
D	Characteristic Width (diameter in the case of a circle)
d	Depth From Mean Sea-Level
$\frac{\vec{dv}}{dt}$	Time Rate of Change of Velocity
$\vec{F}_B$	Buoyant Force
BPL	Buoyant Force per Unit Length
$\vec{F}_{current}$	Current Force
$\vec{F}_D$	Drag Force
$\vec{F}_H$	Hydrodynamic Force
$\vec{F}_I$	Inertia Force
$\vec{F}_{wa}$	Wave Force
$\vec{F}_{wind}$	Wind Force
f	Spar Oscillation Frequency
g	Gravitational constant
h	Total Water Depth ($d + \eta$)
k	Wave Number
L	Characteristic Length
M_B	Moment Resulting From the Buoyant Force
M_H	Moment Resulting From the Hydrodynamic Force
M_O	Moment about the anchor attachment point, o

M_{Wgt}	Moment Resulting From the Spar Weight
m_v	Virtual Mass (1 + hydrodynamic mass)
R_e	Reynolds Number
S	Strouhal Number
T	Wave Period
$\vec{U},\vec{V},\vec{W}$	Directed Fluid Velocities
$\vec{v}_c$	Current Velocity
$\vec{v}_n$	Velocity Normal to the Spar
$\vec{v}_{wind}$	Wind Velocity
$\vec{v}_{wa}$	Wave Particle Velocity
$\vec{v}_{wp}$	Water Particle Velocity
Wgt	Spar Weight
WPL	Spar Weight per Unit Length
X,Y,Z	Orthogonal Coordinate System; Z positive upwards
z_o	Effective Roughness Parameter
ρ	Fluid Density
Θ	Angle of Inclination
η	Free Surface Elevation
σ	Wave Frequency

CHAPTER I

BACKGROUND

I-1 Introduction

The U.S. Coast Guard presently has over 24,000 lighted and unlighted buoys serving as aids to marine navigation in harbors, rivers, lakes and coastal areas across the United States. In addition, a multitude of fixed structures ranging in size from small daymarks to offshore towers are used to "warn the navigator of dangers and oostruction." (U.S. Coast Guard, 1972). While the nature of these fixed aids varies widely, ouoy classification has been standardized based upon their maximum diameter and overall length. Standard lighted buoys are generally made of steel plate and range in size from the small 3 1/2 x 8 feet (1.07 x 2.44 m.) buoy to the large 9 x 32 feet (2.74 x 9.75 m.) shape. Typically, these buoys are held on station by a rectangular concrete block anchor which is connected to the surface floating buoy by an iron chain. In an ideal situation, the length of this mooring chain would be equivalent to the local water deptn. Such a mooring system, however, would not oe very secure as any horizontal forces resulting from either wind, waves or current would quickly move the buoy off station or, if the sinker were large enough, cause it to submerge. Since neither of these alternatives is desirable, the length of a buoy's mooring chain always exceeds the water depth. The length of the mooring chain is dependent upon a host of factors including the average water depth, the maximum current velocity and the size of the buoy itself. The ratio between the mooring chain length and the water depth, or scope, has been found to generally be about 2.5:1. (Bitting, 1976). There are, however, certain high current areas where the scope necessary to securely anchor a buoy

is considerably larger than this nominal value. Such increases in scope result in a subsequent enlargement of a buoy's watch circle (the area on the sea surface whose perimeter is defined by the maximum excursion of a buoy from its anchor). Aside from the economic considerations, increasing a scope and consequently the area of a buoy's watch circle limits the effectiveness of the aid to navigation in assisting "the navigator in determining his position." (U.S. Coast Guard, 1976).

Fixed aids are preferred to buoys because of the positional stability they provide the mariner. Unfortunately, however, floating debris and ice occasionally strike these pilings or fixed aids with sufficient force to damage them. Furthermore, in some instances the lower portion of the broken pile remains submerged while still implanted in the seabed thus imposing a potential hazard to vessel traffic in the area. More frequently, however, these pilings are struck and subsequently broken by barges and other large cargo carrying vessels. That such accidents take place is not surprising when one considers the rather confined quarters of a river or shipping channel as compared with the open ocean, and that barges are frequently rafted together around one tugboat for transport. The effect of such rafting means that both barges and tug move as one massive vessel. Even under the best of conditions, the maneuvering of this assemblage is difficult. When moving downstream, relative to the earth, the relative flow of water past the tug's rudder is reduced by the velocity of the current and consequently steerage control of this tug-barge system becomes all the more difficult. Considering that these piles are often placed in locations where there is a change in the direction of the channel, it is not surprising that these aids are frequently struck or grazed. Besides barge traffic, strong currents have a tendency to scour the bottom thereby creating the possibility

that it will erode the pile where it enters the seabed.

As an alternative, an articulated spar which combines the most desirable features of both standard buoys and conventional fixed aids might be used as a functional aid to navigation in these situations. Such an aid would consist of an anchor, a universal joint or similar attachment mechanism and a rigid member extending from just above the channel bottom through the water column to a relatively short distance above the sea surface. Being free to rotate about its attachment point, such an aid would tilt when grazed by a passing vessel. In addition, debris or flowing ice which might cause a pile to break would simply push the articulated spar aside and continue to move downstream or else force the spar underwater while passing above it. Although such a spar would be free to rotate about its attachment point, its rigidity would restrict its watch circle to a very small area.

I-2 Review of Relevant Literature

The concept of an articulated spar is relatively new to the field of Ocean Engineering, the first of such devices being the product of oil company research. The Elf-Ocean Experimental Oscillating platform is a massive cylindrical articulating structure 21 feet (6.40 m.) in diameter and over 300 feet (91.44 m.) in length. (Villian, 1970). Originally placed on station in August of 1968 in the Bay of Biscay, this platform was designed primarily for oil exploration purposes. In addition, six large cylindrical subsurface floats provide a sufficient amount of buoyancy to make the platform stable enough for general offshore research and data collection purposes as well.

Although considerably smaller in size, another articulated tower which had its origin at about the same time was the Single Point Mooring

(S.P.M.). Also the product of oil company research, these moorings were developed for the loading and unloading of large tankers in severe environments and relatively deep water. Such moorings were designed for the purpose of being a much less expensive and more easily constructed alternative to the deep water berthing facilities necessary to accommodate Very Large Crude Carriers (V.L.C.C.). (Gruy and Kiely, 1977). While somewhat similar in concept to the articulated spar, S.P.M.'s also have some fundamental differences. The first S.P.M. installed at Breqa, Libya in October of 1969 for the Exxon Company serves as an example. (Synodis and Flory, 1977). This S.P.M. essentially consists of an anchor, a universal joint, a riser section, a subsurface buoyancy chamber, a mooring float and some connecting chain. In addition, one or a series of hose sections leads from the swivel joints located at the top of the buoyancy chamber to either the vessel being loaded or, when not in use, to the mooring buoy itself. This configuration is shown in Figure I-1. From this sketch it can be seen that the upper portion of the S.P.M. with its flexiole anchor chain more closely resembles a standard mooring system.

In the early 1970's a series of light beacons known as Sarus Towers were constructed and installed in several countries including Australia, Papua, New Guinea and Indonesia. The Sarus Tower design combines the reliability of a fixed structure with the low capital cost, ease of installation and flexibility of a lighted buoy. Unlike the articulated spar, the main body of the Sarus tower is composed of not one, but three rigid members which are welded together end to end. While the exact dimensions of these towers may vary from site to site, the installation at Port Hedland, on the western coast of Australia serves as an example. (Whitaker, 1975). At this location, the lower

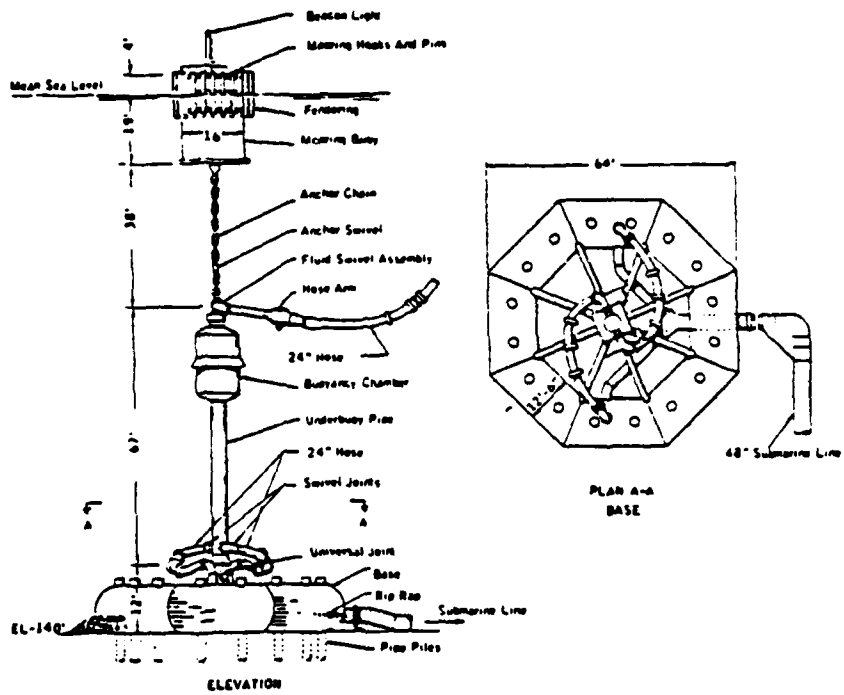


Figure I-1

Diagram of the Brega, Libya Single Anchor Leg Mooring

cylinder is a 42 inch (106.68 cm.) diameter section of 1/2 inch (1.27 cm.) plate steel measuring 25 feet (7.62 m.) in length. The upper cylinder is also made of steel plate and has a maximum diameter of 36 inches (91.44 cm.) which gradually tapers to a minimum diameter of approximately 24 inches (60,96 cm.) at the upper end of its 40 feet (12.19 m.) length. A large subsurface cylindrical buoyancy chamber with dished ends serves to join these two sections. At the Port Hedland installation, the buoyancy chamber has a diameter of 9.5 feet (2.90 m.) and a maximum length of only 7.5 feet (2.29 m.). By compartmentalizing this buoyancy chamber into four sections, one section can become flooded without endangering the buoyancy of the entire structure.

Another group of articulated light beacons are those located at the entrance to Genoa harbor in Italy. At this location, the nearly one mile long entrance channel has been dredged to a depth of approximately 50 feet (15.24 m.) to accommodate large, deep draft tankers. (Dell'Aggio, 1972). However, the width of this entrance channel ranges from 850 feet (259.08 m.) at its seaward end to under 400 feet (121.92 m.) at the jettyhead. Consequently, conventional buoys with scopes of about 2:1 were found to be unsatisfactory for defining the edges of this narrow channel. To solve this problem a series of articulated light beacons were designed and built by the Resinex Company of Iseo, Italy. These beacons are some 56 feet (17.07 m.) in length and from photographs appear to be about 1 foot (0.30 m.) in diameter. They are composed of an anchor, a special spherical steel joint, a galvanized steel pipe and a steel frame platform which is mounted at the surface end of the structure and used for servicing purposes. Like similar structures, a series of subsurface floats fixed at mid-depth provide additional buoyancy and stability, thus reducing oscillation of the structure to a few

degrees. Being located in a relatively protected environment, these beacons were designed to withstand the combined forces of approximately 100 miles per hour (160.93 km./hr.) winds and 16 feet (4.88 m.) seas without excessive heeling.

In addition to being used as stable platforms and aids to navigation, an articulated spar has been successfully designed and constructed to measure oscillatory flow and wave direction. (Lowe et. al., 1974). Using an 8.9 cm diameter air filled, filament wound pipe attached through a universal joint to a bottom anchor, motion was measured by two orthogonally-mounted accelerometers located in the top portion of the spar. Moored in 33 feet (10.06 m.) of water, this spar behaved as a forced, damped oscillator. Spectral analysis of the accelerometer records showed that for wave periods less than 10 seconds, the tilting spar showed reasonable agreement with a computer simulation model of its behavior. At larger wave periods the model predicted tilt angles which were too low. It was conjectured that this was the result of the computer model's use of constant drag and inertia coefficients.

Excluding Lowe's tilting spar used for wave measurements, all of the aforementioned devices have been located in water depths of 40 feet (12.19 m.) or greater. To the author's knowledge, no proposed designs and/or constructions of articulated spars in the 15 to 30 feet (4.57 to 9.14 m.) water depths, typical of river channels, currently exist in the literature. Without exception, the greatest design force imposed upon any of these existing structures is the result of wave action. In the relatively confined area of a river or shipping channel where the proposed articulated spar device would be employed, however, current forces are expected to be the most important design consideration.

CHAPTER II

THE ANALYTICAL MODEL

II-1 INTRODUCTION

An analytical model which computes the total force, resultant moment and list angle of a spar device with either a circular or elliptical cross-section in the presence of wind, current and wave forces has been developed. In the sections that follow, a detailed derivation of this analytical model is presented.

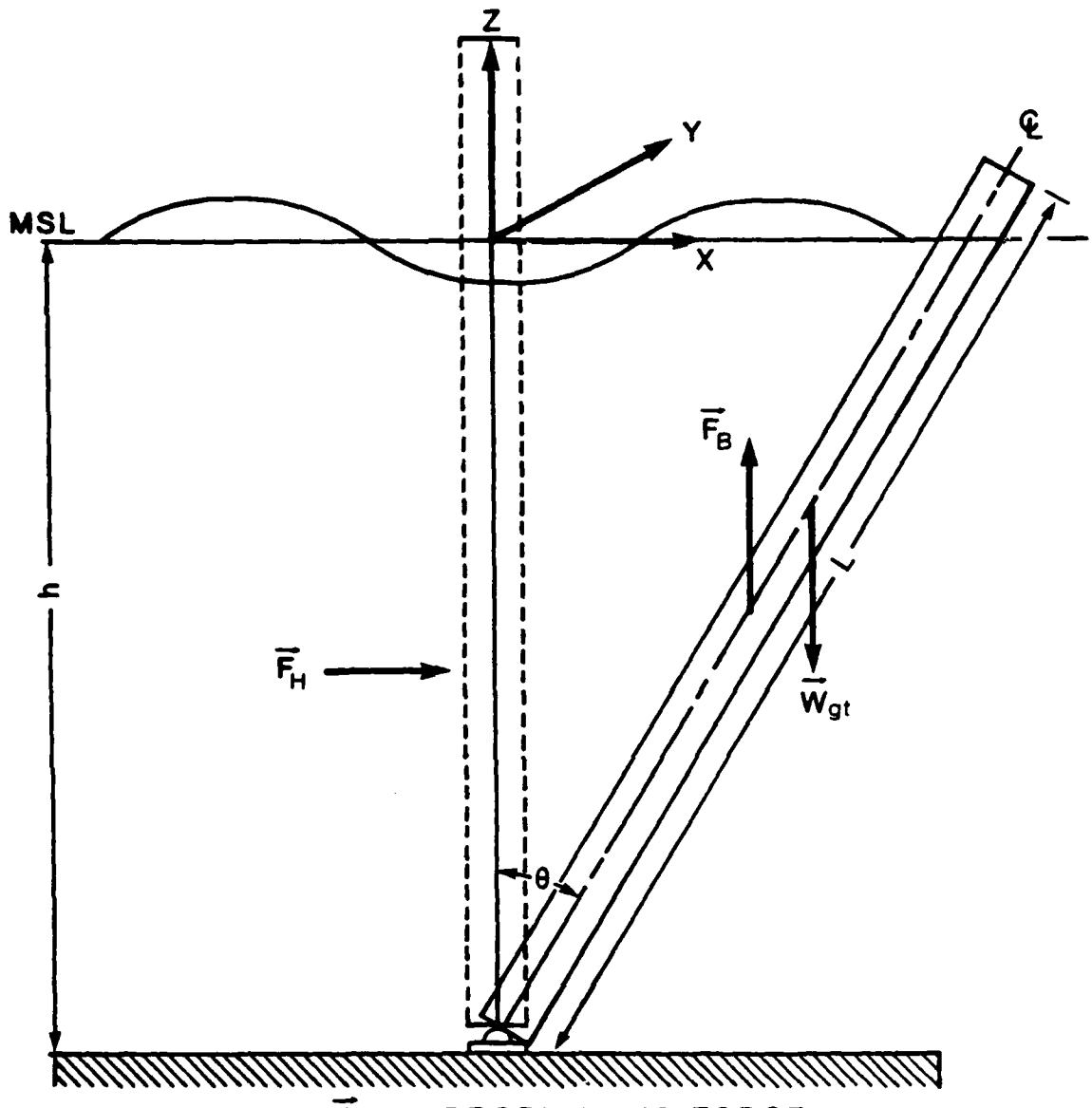
II-2 Overview

II-2.1 Theoretical Considerations

In dealing with the forces on a three-dimensional structure such as a spar, it is important to establish a coordinate system and fix its location in space. The origin of the coordinate system used in this analysis is the geometric center of the spar cross-section defined by the still water surface at zero angle of inclination, θ, as shown in Figure II-1. The velocity components U,V, and W correspond to velocities, in the X,Y, and Z directions respectively with the Z axis being defined as positive upwards.

A combination of wind, current and wave forces are considered to be acting on the articulated spar in this analysis. Since the time responses of this spar system to changes in the current forces, the most critical for the proposed application, are shorter than the time rate of change of the current field, dynamic effects are assumed to be unimportant to this analysis. Consequently, this analysis assumes the articulated spar to be in a state of static or quasi-static equilibrium.

Fluid particles traveling past a fixed body exert both normal and tangential forces on it. Under conditions of static equilibrium, the



$\vec{F}_H$- HYDRODYNAMIC FORCE

$\vec{F}_B$- BUOYANT FORCE

$\vec{W}_{gt}$ - SPAR WEIGHT

θ - SPAR ANGLE OF INCLINATION

FIGURE II-1 DEFINITION SKETCH OF THE COORDINATE SYSTEM

body must remain stationary, requiring that the summation of forces and moments must be zero:

$$\Sigma\vec{F} = 0 \tag{1}$$

$$\Sigma M_o = 0 \tag{2}$$

where o may be any point on the body. The forces on the spar in Figure II-1 may be described in vector form by

$$\Sigma\vec{F} = 0 = \vec{F}_H + \vec{F}_B + \vec{W}gt \tag{3}$$

where $\vec{F}_H$ is the hydrodynamic force composed of a drag and inertia component following the approach of Morison, et. al. (1950), $\vec{F}_B$ is the buoyant force and $\vec{W}gt$ is the spar weight. It should be noted that the hydrodynamic force, $\vec{F}_H$ also includes the force of wind on the exposed portion of the spar. Similarly, the moments about any point o may be described by

$$M_o = 0 = M_H + M_B + M_{Wgt} \tag{4}$$

where the subscripts are the same as those used in Eq. (3). By applying these two fundamental principles of statics to this analysis, the list angle, θ, of the articulated spar device may be resolved. A further term could be added to Eqs. (3) and (4) to represent a lumped mass such as might occur if light signal equipment and daymarks were added to the spar or to denote additional floatation.

In this analysis, the wind velocity is assumed to act on that portion of the spar which is above the still water surface to induce the wind force shown in Figure II-1. Similarly, a combination of current and wave particle velocities and accelerations are assumed to act on the submerged portion of the spar inducing the hydrodynamic force also shown in Figure II-1. By convention, these wind, current and wave particle velocities and accelerations are resolved into components normal and tangential to the spar. In addition to these two normal hydrodynamic forces, the buoyant force acts vertically upwards from the center of buoyancy and the weight acts vertically downward from the center of gravity as described in Equation (3). Once these forces are resolved, moments are taken about the anchor attachment point. In the convention adopted in this analysis, the overturning moment created by the wind and water particle forces acts clockwise while the righting moment resulting from the buoyant force acts counterclockwise as shown in Figure II-1.

The total hydrodynamic force on the spar may be described by the Morison equation as

$$\vec{F}_H = \frac{1}{2}\rho A_p |\vec{v}_n| \vec{v}_n C_D + \rho A_c L \frac{\vec{dv}}{dt} C_M \qquad (5)$$

where the first term on the right hand side is the drag force and the second term the inertia force. In the drag force term of Equation (5), ρ is the fluid density, A_p is the projected area normal to the flow, $\vec{v}_n$ is the velocity normal to the object and C_D is a dimensionless drag coefficient. The absolute signs are included to preserve the directionality of the resulting force term. The inertia portion of the total hydrodynamic force is composed of ρ, the density of the fluid, A_c the cross-sectional area of the body, L, the length of the body, $\frac{d\vec{v}}{dt}$, the

local fluid acceleration and C_M the hydrodynamic mass coefficient.

II-2.2 Steady Flow Forces

Over a time period on the order of minutes, those forces induced by reasonably steady winds and currents may be considered steady while those induced by waves will be time dependent. Consequently, for these steady flow forces, the $\frac{d\vec{v}}{dt}$ term is zero and, therefore, the total wind and current forces may be completely described by their drag component. Thus

$$\vec{F}_{wind} = \frac{1}{2} \rho A_p |\vec{v}_{wind_n}| \vec{v}_{wind_n} C_D \tag{6}$$

$$\vec{F}_{current} = \frac{1}{2} \rho A_p |\vec{v}_{c_n}| \vec{v}_{c_n} C_D \tag{7}$$

In this analysis, one may specify the fluid in which the spar is immersed as either fresh or salt water. Although the density of brackish river water is a function of salinity and temperature, the variation in these properties is small over the range of variation expected and as a result, this value is assumed to be constant. The density values of air and water selected for use in this model are defined at a temperature of $68^{o}F$ ($20^{o}C$).

It is well known that near a surface such as land or water the wind velocity profile over that surface is not uniform but varies with both time and altitude. Ignoring the time scale variations, the wind velocity profile in this model is assumed to follow the well known Prandtl-von Karman universal velocity distribution law:

$$\frac{\vec{U}_a}{\vec{U}_{10}} = \frac{\ln (z/z_o)}{\ln (10/z_o)} \tag{8}$$

where z is the height of measurement in meters and z_o is an effective roughness parameter. Since only large velocity winds are expected to significantly effect a spar's list angle, a z_o value of .003 m. as suggested by Myers,et.al. (1969) for strong winds is used in this model.

As a result of this assumed distribution, the wind speed used as input to this computer model must have an elevation associated with it. Based upon this one wind data point, an entire wind profile including the velocity at the 10 meter level is determined. Furthermore, this 10 meter wind velocity value is used as input to the Sverdrup, Munk and Bretschneider (S.M.B.) computations described below.

II-2.3 Wave Induced Forces

In order to determine the total water particle force on a structure using Equation (5), it is necessary that the horizontal and vertical particle velocities and accelerations be known. Unlike the wind and current velocities which are easily measured, the wave velocities and accelerations required for this analysis are often estimated using simple wave theory. The question as to which wave theory to apply to determine the appropriate values for use in the Morison equation has been studied extensively. Patton (1966) states that for a body that is small compared to the wavelength, the water wave may be adequately described by Airy wave theory. Dean (1967) has shown that higher order Stokes theories (3rd and 5th) as well as Cnoidal wave theory are not uniformly more applicable than Airy theory. Further, Dean points out that Airy wave theory satisfied the kinematic boundary conditions at the surface much better than these higher order theories for shallow water waves (Edge and Myer, 1969). In general, the literature seems to support the premise that for most applications, the well known Airy formulations for particle

velocity and acceleration are the most logical for substitution into the Morison equation. Using Airy theory, the horizontal and vertical components of the local fluid particle velocity, $\vec{U}$ and $\vec{w}$ respectively, are:

$$\vec{U} = \frac{agk}{\sigma} \frac{\cosh k\ (h + z)}{\cosh\ kh} \sin\ (kx - \sigma t) \tag{9}$$

$$\vec{w} = \frac{agk}{\sigma} \frac{\sinh k(h + z)}{\cosh\ kh} \cos\ (kx - \sigma t) \tag{10}$$

where g is the gravitational constant, k is the wave number, and σ is the wave frequency. The local fluid acceleration terms in the horizontal and vertical directions may be found by differentiating Eqs. (9) and (10) with resoect to time, t, resulting in

$$\frac{\partial \vec{U}}{\partial t} = -agk \frac{\cosh\ k\ (h + z)}{\cosh\ kh} \cos\ (kx - \sigma t) \tag{11}$$

$$\frac{\partial \vec{W}}{\partial t} = -agk \frac{\sinh\ k(h + z)}{\cosh\ kh} \sin\ (kx - \sigma t) \tag{12}$$

Equations (9) to (12) have two parts: an amplitude term and a phase term. The phase term in each describes the oscillatory nature of the wave particle velocity and acceleration. The amplitude term in each equation is composed of a constant part and a hyperbolic part. This hyperbolic portion accounts for the exponential decay of the horizontal and vertical velocity and acceleration components with increasing water depth. h in these equations is the time dependent total depth which is defined as

$$h = d + \eta \tag{13}$$

where d is the still water depth and η is the corresponding wave height defined by

$$\eta = a \cos \frac{2\pi t}{T} \tag{14}$$

where a is the wave amplitude and T the wave period.

Because of the nonlinearity of the drag coefficient used in these drag force determinations, the total water particle force may not be determined by the superposition of the current and wave forces (Wu and Tung, 1975). Rather, this total water particle force must be determined by first vectorally summing the individual velocity components and then substituting this resultant water particle velocity into the drag force term of the Morison equation. Thus the water particle force may be defined by

$$\vec{F}_{wp} = \frac{1}{2}\rho A_p |\vec{v}_{wp_n}| \vec{v}_{wp_n} C_D + \rho A_c L \frac{d\vec{v}}{dt} C_M \tag{15}$$

where the water particle velocity, $\vec{v}_{wp}$, is defined as

$$\vec{v}_{wp} = \vec{v}_c + \vec{v}_{wa} \tag{16}$$

where $\vec{v}_c$ is the current velocity and $\vec{v}_{wa}$ is the water particle velocity.

In this analysis, however, no consideration is given to the possible interaction effects between wave induced and current velocities. Such

interaction effects have been examined in detail by Jonssor, et. al. (1970). When a current and waves are traveling in the same direction, for example, wave length tends to increase and height and period tend to decrease. These effects have been considered significant enough that they have been accounted for in the design of North Sea oil drilling platforms where waves are the dominant forces on the structures. (Mes, 1977). However, since the use of a wave correction factor to account for these interaction effects necessitates the use of an effective average current value, this formulation was not included in the analytical model.

The waves in this analysis are assumed to be wind generated and consequently act in the same direction as the wind. When considering wave forces, input data is either supplied in terms of wave height and period or can be calculated using the S.M.B. method.

II-2.4 Drag Coefficient Determination

A cylinder with a circular cross-section is the most common structural element in the ocean and as a result a great many experiments both in the laboratory and in the field have been performed in an effort to define precisely the drag and inertia coefficients of the Morison equation. The general procedure followed in these experiments has been to measure the forces on the structure as well as the wave and current conditions. Using a suitable wave theory, the water particle velocity is subsequently computed. The results of these experiments, however, differ widely. (Bretschneider (1957), Agerschou and Edens (1965), Wieselburger (1968), Keulegan and Carpenter (1956), etc.). Since it is necessary to employ a wave theory to calculate the water particle kinematics from the measured surface profile, the resulting range in these coefficient values reflects not only possible inaccuracies in the Morison formulation but in

the wave theory used as well. More significantly, it was discovered that even in a series of identical waves, scatter was found in the wave forces measured. Further analysis has shown that this wide scatter in the published data is related not only to the wave theory selected and the accuracy of the measurement system but also to the roughness of the pile, local currents, vibrations in the test piles, the proximity of neighboring piles and other effects. The U.S. Army Coastal Engineering Research Center has examined a great deal of this data in an attempt to simplify the problem of selecting the proper data set and have subsequently developed a recommended design curve. This curve, shown in Figure II-2, has been incorporated into this analytical model for application when dealing with circular cylinders. One should note for purposes of comparison, Figure II-2 also presents results of some laboratory and field measurements of drag coefficients.

In Equation (5), it was shown that the drag coefficient is not only a function of Reynolds number but roughness and length effects as well. Further it was pointed out that data regarding these effects is generally obtained in separate analyzes to establish trends. In the case of the dimensionless spar length-to-diameter ratio (L/D), it has been observed that the importance of this parameter increases as the spar length decreases. In such cases, the pressure at the end(s) of the spar is relieved since water is allowed to flow around the end of the spar rather than being forced to one side of it. Consequently, as the (L/D) ratio decreases so does the drag coefficient. However, empirical data regarding this effect has only been documented for Reynolds numbers in the range 10^4 to 10^5. Furthermore, this ratio has been shown to be most significant for small [< 10] (L/D) ratios. By contrast the articulated spar considered in the analytical model is generally expected to have an

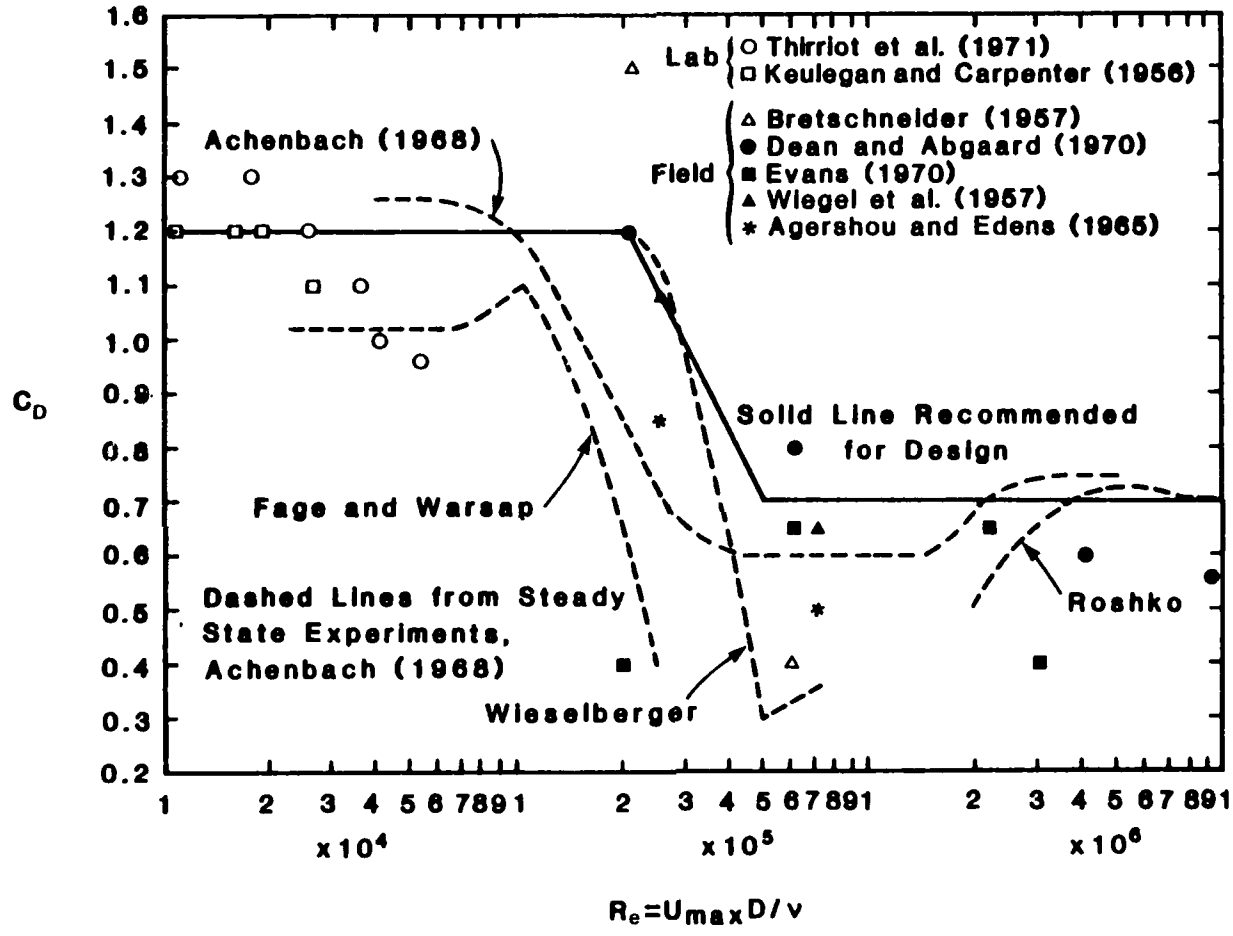


FIGURE II-2 THE SHORE PROTECTION MANUAL RECOMMENDED DESIGN CURVE FOR THE VARIATION IN DRAG COEFFICIENT WITH REYNOLDS NUMBER FOR CIRCULAR CYLINDERS (U.S. ARMY CORPS OF ENGINEERS, 1973)

(L/D) ratio larger than 10 thus minimizing this effect.

In general, roughness elements tend to increase the effective characteristic dimension of a body and thereby effectively increase its Reynolds number. In the circular cylinder case, decreased roughness tends to result in the transition from laminar to turbulent flow occurring at lower Reynolds numbers. In addition because of the effectively increased projected area, the total drag force on such a cylinder is larger than if the roughness elements were absent. While such effects have been measured experimentally, the present analysis assumes the spar to be smooth and thus ignores these effects.

Drag coefficient information on an elliptical shape is by contrast almost non-existent. Some of the earliest drag coefficient information on this shape was reported by Prandlt (Daugherity and Franzini, 1977). Unfortunately, however, this information only examined an ellipse whose major-to-minor axis ratio was 4:1. In addition, the drag coefficient was determined only over a small range of Reynolds numbers from about 3×10^4 to 3×10^5. Hoerner (1965), after examining published data as well as performing his own experiments, developed a series of empirical relationships for the drag coefficient on an ellipse based upon Reynolds number considerations as well as the major-to-minor axis ratio of the ellipse. For flow parallel to the major axis these relationships were employed in the analytical model to compute an appropriate drag coefficient.

In regard to flow in the minor axis direction, no data could be found in the literature regarding the drag coefficient on such a section. However, it was noted that such a section generally resembles a flat plate and as a result a drag coefficient value of 2.0 was assigned arbitrarily for flows in this direction. While such a value may be rather large, in

a directionally uniform flow field, a spar would align itself with the current and thus not respond to these off-axis flows. However, if vertical shear were present in the water column, resolving the various velocities acting on the spar into components results in only a small portion of any off-axis flow being actually incorporated into the formulation of this potentially large drag coefficient value. Furthermore, since any off-axis flow would also generate some lift on the spar, the use of such a large drag coefficient value represents a poor attempt at including this effect. Generally the lift on a wing section for angles of attack below stall is proportional to the sine of the angle of attack. Unlike a wing section, however, the elliptical spar section is symmetric about its minor axis and has a blunt trailing edge which acts to reduce streamlining effects. Consequently, the coefficient of lift of such a section would be much smaller than that of an airfoil shape. Therefore, because of a lack of adequate lift and drag information as well as the comparatively small likelihood of large off-axis flows, a minor axis drag coefficient value of 2.0 was adopted.

Nearly all of the previous studies which define the drag coefficient on a circular cylinder attempt to quantify the inertia coefficient as well. Like the drag coefficient data, a great deal of scatter exists in this inertia coefficient information also. Unfortunately, no published data or empirical relationships could be found relating this coefficient to some measurable spar parameter. Consequently, the analytical model employed the potential flow formulation for the inertia coefficient of an ellipse:

$$C_M = (1 + B/A) \qquad (17)$$

where A and B are the major and minor axis lengths of the ellipse, respectively. Since a circle represents a special case of an ellipse where the two axes are of equal length, this formulation reduces to the correct potential flow value of 2.0. Generally speaking, potential flow values of C_M tend to be somewhat higher than those measured in the field. Consequently, the forces and resulting list angles computed using these potential flow values will tend to result in a somewhat conservative design formulation.

II-3 Computer Model Description

The forces, moments and list angle of an articulated spar device are calculated according to the procedure described above. Using Equations (6) and (15), this computer model consists of a main program, ASB1, and 19 internally called subroutines. Written in Fortran IV, this program has been run successfully on the University of Rhode Island's ITEL 5 digital computer. In developing this model, every effort has been made to keep this program as general as possible, and as a result the program accepts a wide variety of input. The large number of arrays which may be needed by this program require that 320k bytes of core be allocated for its execution.

A flowchart summarizing the major steps in the program is shown in Figure II-3. Initiation of this computer model starts by defining a series of fluid, physical and environmental parameters which are described in detail in the users manual (Appendix B). In summary, the first set of input variables serves to define the basic fluid properties of viscosity and density as well as the water depth in which the spar is located. The physical dimensions and material properties of the spar including the orienting vane, if present, are the next parameters to be

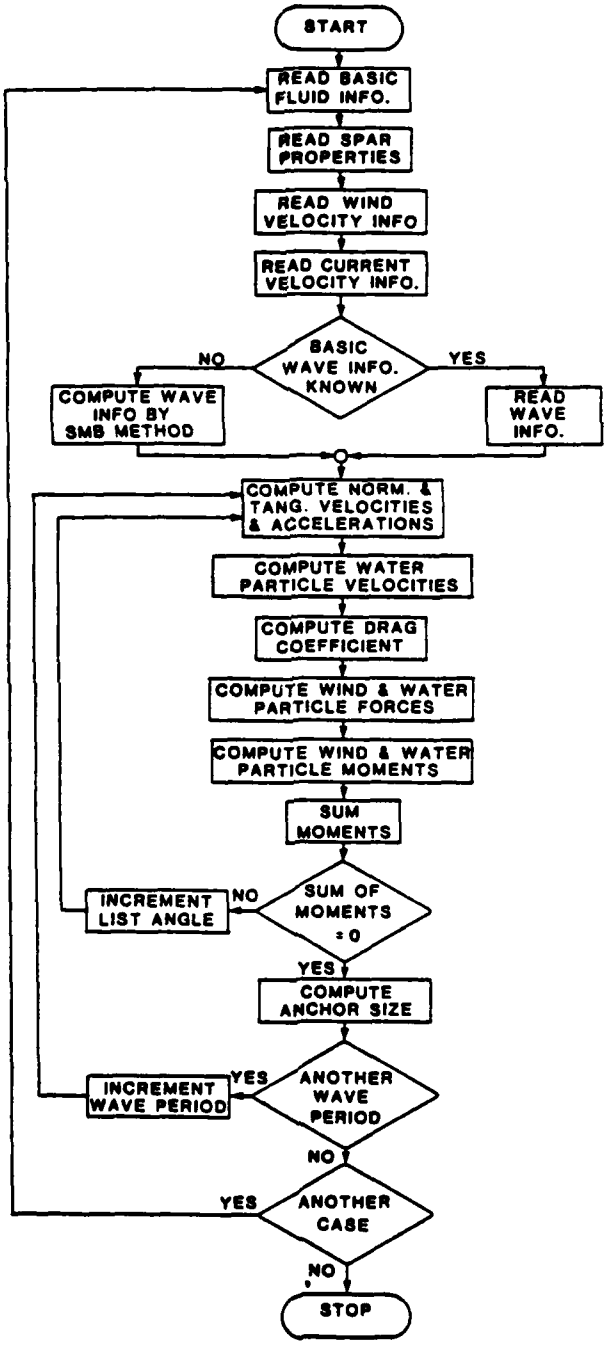


Figure II-3

Summary Flowchart of the Analytical Model

defined. This is followed by a description of the distribution of the velocities acting on the spar. Following the input of this environmental information a series of subroutines are called which compute information that remains unchanged by variations in the spar's list angle. From these subroutines, such information as the weight of the spar in air, a variety of wave information and the wind velocity profile are obtained.

Since the distribution of velocities on the spar may have large spatial variations in the vertical, the spar is divided into a number of elemental areas. By computing the total force of each of these areas and then summing over the entire length, the total force acting on the spar may be computed. Since the variation in one driving force profile may be much larger than that of another, three sets of areas, one for each force, are initially defined. However, because the wave and current velocities must be combined in order to determine the water particle force, this number of area sets is reduced to two; one for the wind forces and the other for water particle forces. In this reduction scheme, the maximum number of equal area elements describing the current and wave particle velocities is selected.

Having defined the driving force velocity profiles acting on the spar, its orientation relative to magnetic north is ascertained based upon a hierarchy structure. In this hierarchy, the force due to current is assumed to predominate over those caused by wind and waves. The coordinate system described above is fixed to the spar and as a result, the bearing of the buoy relative to magnetic north can oe determined. The computer program assumes that the spar will orient itself such that its major axis is parallel to the direction of the flow. Further, an orienting vane present on the structure will always act as the trailing edge, thereby fixing the orientation of the spar relative to the forces

acting on it.

Once the orientation and number of elemental areas has been determined, the relative normal and tangential velocities, and in the case of waves, accelerations acting on each of these areas in the X and Y directions are determined. Using these normal velocities to first compute a series of elemental Reynolds numbers, an associated drag coefficient for each element is computed using one of the previously described empirical relationships. Subsequently, the force on each of these elemental areas is determined from Equations (6) and (15). By summing these elemental forces, the total wind and water particle force acting on the spar is computed.

These driving forces produce an overturning moment which is computed next. Buoyancy forces produce a righting moment which acts in opposition to this overturning moment. Once these two moments have been calculated, they are compared in the main program. Depending upon which of the two moments predominate, the list angle is altered and the computational process, starting with the determination of the normal and tangential velocities and accelerations, is repeated. When the two moments are equal or nearly so, depending upon the convergence criteria specified, the computation is complete. At this time the wave time step is incremented by one and the general computational process is repeated.

When the forces, moments and list angles have been determined for all of the wave time steps then one final subroutine is called. This subroutine selects an appropriate anchor for the spar based upon the maximum net buoyant force seen by the spar during one wave period. In addition a factor of safety for this anchor is determined. The program then checks the input data file to determine if there are additional cases to be computed. If appropriate, a check is made to determine if during the

next analysis only the environmental parameters will be altered or if the physical dimensions of the spar will also be changed. By returning to the appropriate location, the new data is input to the main program and the computational process is repeated. When no further data is supplied to the program, it terminates.

II-4 Sensitivity Analysis

II-4.1 Introduction

It is clear that the analytical model which has been developed is of a very general nature and consequently a sensitivity analysis to cover all contingencies could not be made. Therefore, in order to determine the relative importance of the various physical and environmental parameters present on a spar's list angle, one must make some assumptions about the nature of these possible conditions. The first step in the process was to determine the significant forces involved and then attempt to ascertain the relative importance of the physical and environmental parameters influencing these forces.

II-4.2 Analysis of Forces

The analytical model previously developed allows for the action of wind, wave and current forces to act upon a spar. In the present analysis, it is envisioned that an articulated spar designed using this model would be placed in the relatively confined area of a river or shipping channel as described in Chapter I. In such a situation, current velocities could be on the order of 2 to 3 knots or greater. The significance of wind forces in such a situation is best illustrated by the following example. An exceptionally strong wind of 75 miles per hour (120.70 km./hr.) is equivalent to a velocity of 110 ft/sec. The force created by

such a wind velocity, however, is smaller than that created by a current velocity of 3 knots (5.1 ft./sec.), on an equal area basis. For example, on a one square foot area, with an assumed drag coefficient of 1.0, the wind would produce a force of 28 pounds (12.73 kg.) while that created by the 3-knot current would be 51 pounds (23.18 kg.). Aside from the large velocity differential, the difference in the magnitude of these two forces is the result of density differences: that of water being approximately 1000 times greater than that of air. More significantly, while such current velocities are expected to be common in the location where such a spar might be used, the wind speed used above is representative of hurricane force winds and thus represents an extreme case. Further, since much of an articulated spar is assumed to be submerged, the area on which the current force acts will be significantly larger than that exposed to wind forces. Consequently, under normal conditions, when small daymarks are used, it is reasonable to assume that in comparison with current forces, wind forces may be neglected.

In general, it is possible to omit from consideration, the action of wave forces on the spar as well. For example, consider the wave forces created by a large, but not excessive, wind velocity of 40 miles per hour (64.37 km./hr.). Such a velocity will, over a fetch of 10,000 feet (3.05 km.) in 30 feet (9.14 m.) of water, produce a wave with a significant height of 2.5 feet (0.76 m.) and significant period of 3.0 seconds as predicted by the S.M.B. method. Based upon Airy theory, such a wave would result in a maximum horizontal particle ve' city of 2.6 feet per second (0.79 m./sec.). While this value is approximately 50% of the 3 knot (1.55 m./sec.) current velocity, several factors should be considered. First, such a wind velocity and fetch condition, while not rare, is still exceptional in the semi-enclosed areas in which this articulated

spar would be used. More importantly, this velocity represents a maximum surface condition and while such a force at this location would produce a sizable moment, this force is exponentially decreasing with both time and depth. Consequently, based upon the scenario developed in Chapter I, combined with the likelihood of forces of this magnitude occurring, wave forces on a spar in comparison with the expected current forces are generally small and may therefore be eliminated from further consideration. As a result of this discussion, current forces may be considered the dominant and only significant force acting on this articulated spar device.

A parametric sensitivity analysis was performed on many of the physical and environmental parameters which effect the overall list angle of the spar. As this analysis proceeded, it became apparent that because of the large number of variables involved, different spar configurations might result in very different sensitivity results. In general, by varying one parameter while keeping all others constant, trends would be established, but quantitative assessment of the various differences was limited to discussion of a single design. Consequently, the parameters effecting the overall list angle of a spar buoy are most meaningfully assessed in a qualitative rather than quantitative sense. Table II-1 is a list of a variety of physical and environmental parameters with a qualitative assessment of their influence on a spar buoy's overall list angle. These influences are rated as either significant, moderate or slight and are based upon numerous computer simulations under a multitude of conditions. Table II-1 serves further to demonstrate the value of this analytical model. For a given situation where many of these parameters are either limited or fixed due to certain constraints, the user may alter the remaining parameters within whatever physical and

TABLE II-1

INFLUENCE OF VARIOUS PARAMETERS ON A SPAR'S LIST ANGLE

Parameter	Influence
current velocity	significant
spar weight per unit length/buoyant weight per unit length	significant
spar length/water depth ratio	moderate
cross-sectional area	moderate
major to minor axis ratio	moderate
wind velocity	slight
wave height	slight
anchor attachment offset	slight

environmental conditions dictate to obtain a better design for a given situation. Table II-1 may therefore be used as a guide as to the effect of varying those parameters which in a given situation may be altered.

Of the parameters presented in Table II-1, the current velocity and the WPL/BPL ratio where WPL is the spar weight per unit length and BPL is the buoyant force per unit length, were judged to effect significantly the spar's list angle. Figure II-4 shows the effect of changes in the WPL/BPL ratio for circular cylinders with an L/h ratio of 1.3, where L is the spar length and h is the local water depth. At low velocities, it can be seen that the spar is very sensitive to changes in the WPL/BPL ratio, while at large velocities this effect is less significant. Total spar submergence occurs at a list angle of 39.7^{o}. Visibility considerations dictate an upper limit on WPL/BPL of approximately 0.65. Spars with ratios greater than this value will have such incrementally small amounts of reserve buoyancy per foot that their list angle in any current would be excessive. Material properties and structural considerations govern the lower limit of this ratio.

Figure II-5 shows the effect of various L/h ratios on the list angle of a circular spar in various uniform current fields. It can be seen in this figure that at small velocities the variation in L/h is most significant while at large velocities a spar's list angle is less dependent on this ratio. In a given water depth as the spar length is increased so is its overturning moment, due to the additional weight. To compensate for this increased overturning moment, the spar must submerge a greater portion of its length. Hence, for a given velocity, spars with large L/h ratios exhibit greater list angles than those with small L/h ratios. Therefore, to minimize its list angle, a spar should have as small an L/h ratio as possible. However, the use of excessively small L/h ratios

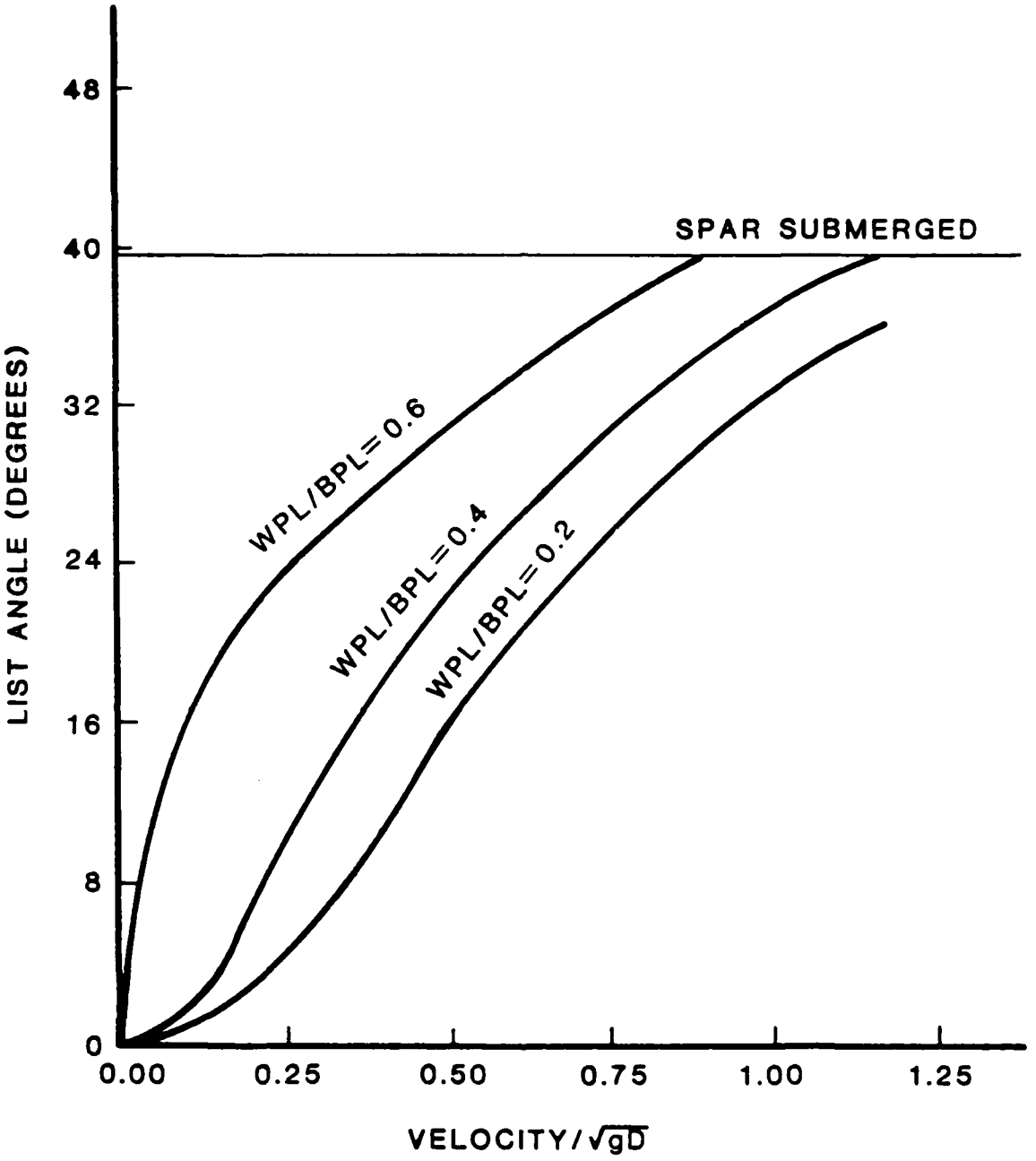


FIGURE II-4 INFLUENCE OF CURRENT ON CIRCULAR CYLINDERS OF VARIOUS WPL/BPL RATIOS L/h = 1.3

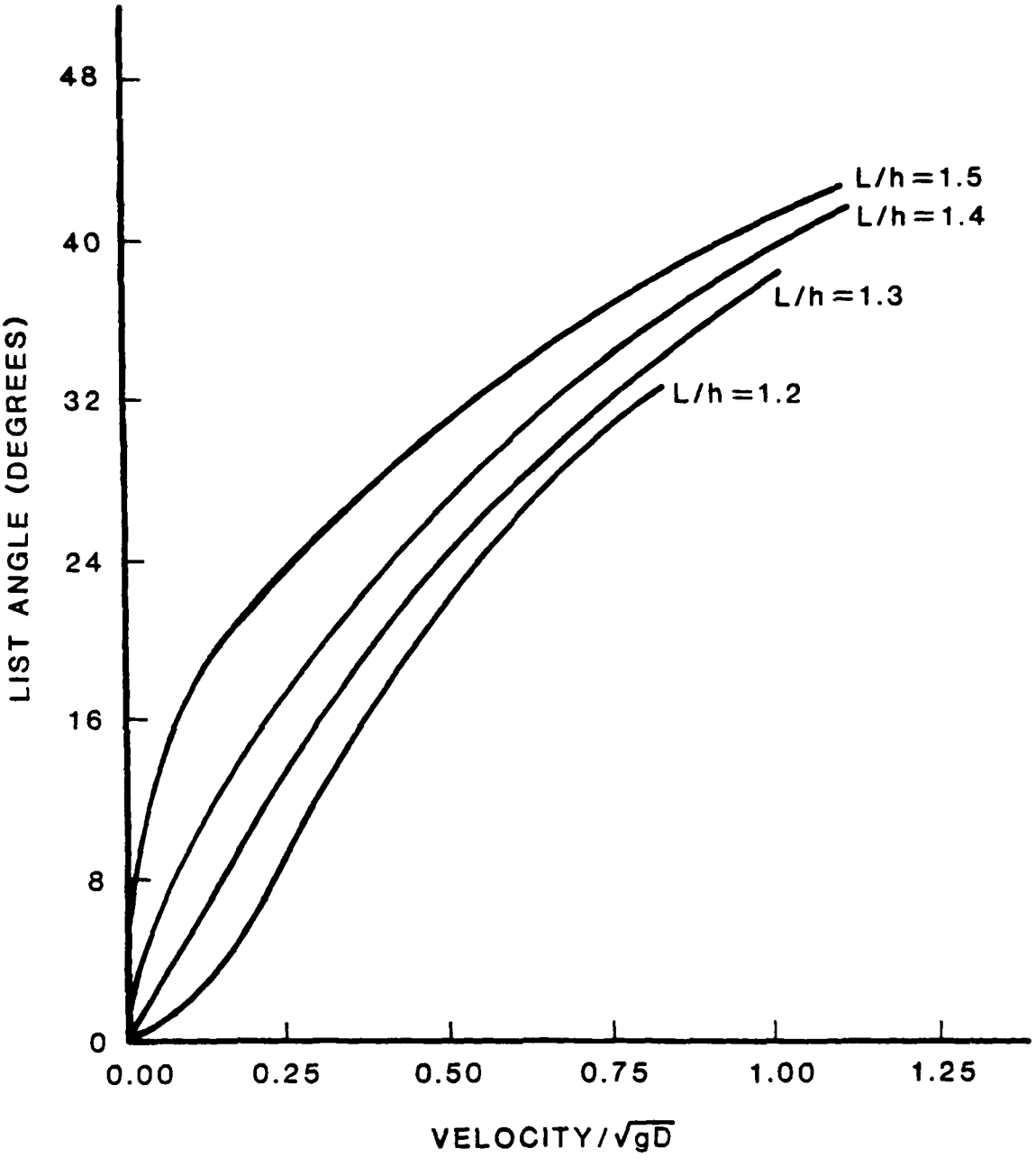


FIGURE II-5 INFLUENCE OF CURRENT VELOCITY ON CIRCULAR CYLINDERS OF VARIOUS L/h RATIOS WPL/BPL=0.446

(i.e., approaching 1.0) results in a spar becoming submerged sooner than spars with large values of L/h. For example, in Figure II-5, the L/h = 1.2 line terminates at a dimensionless velocity value of 0.75 and the L/h = 1.3 line terminates at a dimensionless value of 1.05, indicating the total submergence of the spar. By comparison, spars with L/h values of 1.4 and 1.5 become totally submerged at dimensionless velocities greater than those shown in this figure.

The effect of changes in the major-to-minor axis ratio, A/B, on spars of constant projected area with a fixed L/h ratio is shown in Figure II-6. It can be seen in this Figure that significant reductions in list angle can be achieved by changing the A/B ration from 1:1 (a circular cross-section) to 2:1. Further streamlining of the elliptical shape from a 2:1 axis ratio to a 3:1 ratio results in less significant reductions in spar list angle. In addition, any off-axis flow condition would be subject to large projected areas at these large A/B ratios. As a result of this analysis, an ellipse with a 2:1 A/B ratio was selected for prototype testing.

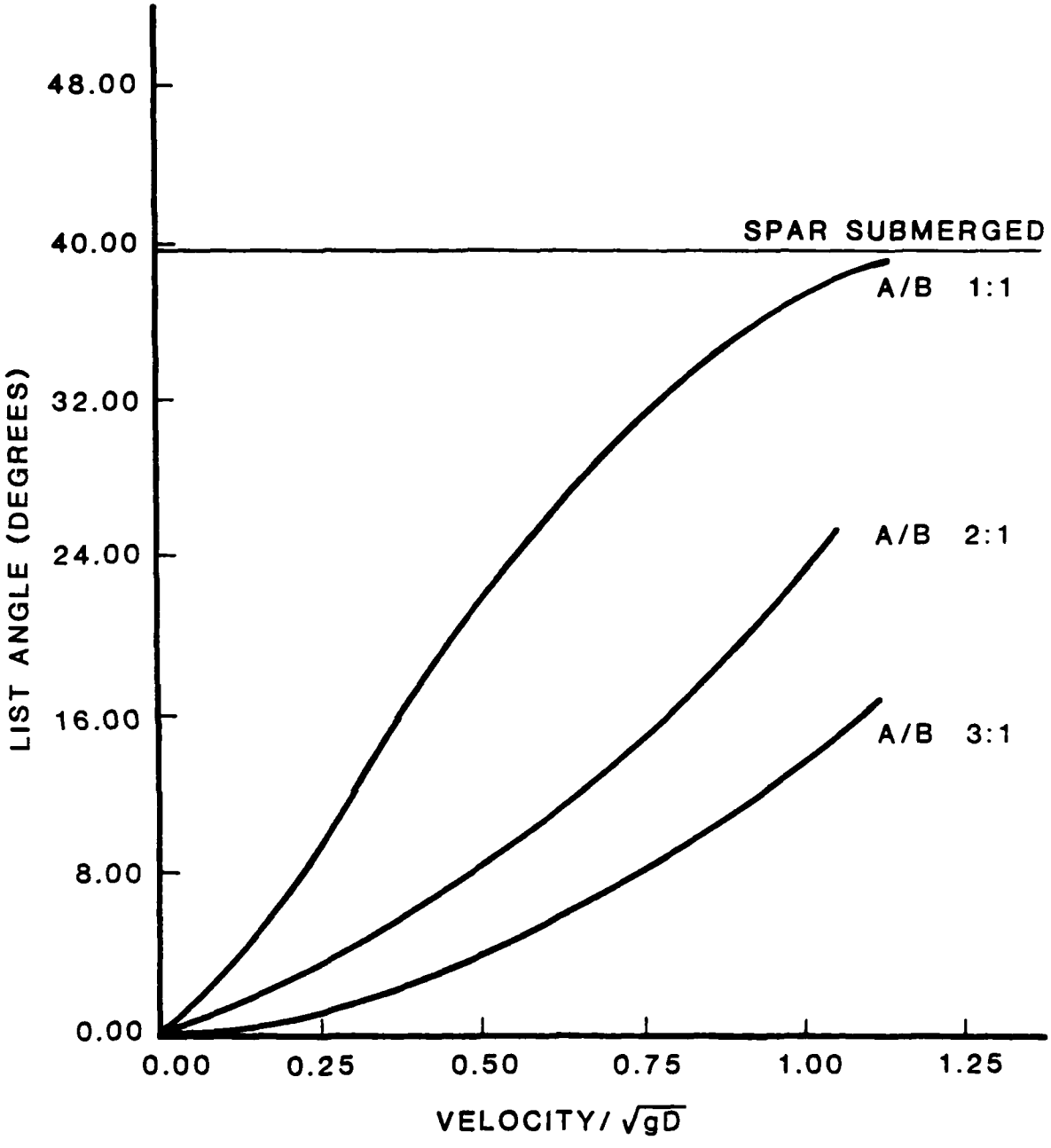


FIGURE II-6 INFLUENCE OF CURRENT VELOCITY ON VARIOUS A/B RATIOS CONSTANT PROJECTED AREA

WPL/BPL = 0.446

L/h = 1.3

CHAPTER III

PROTOTYPE TESTING

III-1 Introduction

The validity of any analytical model is governed by its ability to describe the actual situation being studied. For the purpose of obtaining validation data for this analytical model, a series of laboratory tests using several different spar shapes were performed in the circulating water channel at the U.S. Coast Guard Academy.

III-2 Description of Facilities

The circulating water channel used in these tests is a two-story high, primarily stainless steel structure located in MacAllister Hall on the grounds of the U.S. Coast Guard Academy in New London, Connecticut. Designed at the University of Michigan by Vern Phelps and Francis Ulgive, this system is powered by an axial flow propeller pump. By adjusting the propeller speed, velocities up to a maximum of 10 ft./ sec. (3.05 m./sec.) can be obtained in the channel. In addition to being able to select the current value, plexiglas viewing ports on the side and bottom of the circulating water channel's 10.0 x 4.0 x 2.0 feet (.305 x 1.22 x 0.61 m.) of usable work space allow the user to observe the object under study from many different angles. In addition, colored dye is available for use in observing general flow patterns around objects. To provide for the study of objects which must be anchored, such as this articulated spar, a series of screw holes are located in several places on the bottom of the work area. With more than one location available at a given time, for comparison purposes, two potential spar shapes could be observed together in the same flow. Because of these facilities several spar shapes and a variety of orienting devices could be tested quickly and

easily.

Current velocity measurements in the circulating water channel were made using a Teledyne-Gurley Model #625 6-cup pygmy current meter. When in use, this current meter is positioned on a steel rod which is also mounted on a cross-bar across the tank opening. A hand held revolution counter connected directly to this steel rod allows for the direct determination of the average flow rate over any known time interval.

III-3 Model Descriptions

Initially, two prototype shapes, one with an elliptical cross-section and the other with a circular cross-section, were constructed for testing purposes. Later, a third spar with a more streamlined airfoil shaped cross-section was built. Figure III-1 is a photograph of the three spar shapes which were tested.

Each of the prototype spars was constructed from a styrofoam-type material. Initially a template of the desired cross-section was constructed and used as a pattern for tracing onto the foam board. Subsequently, thirty, approximately 1 inch (.54 cm.) thick foam pieces of a given cross-section were cut and then fiberglassed together to obtain the desired spar shape. Each of these shapes was then sanded to remove any discontinuities, and a bottom attachment plate of 1/4 inch (0.64 cm.) thick plywood was glued to the bottom of each spar. In this way, ball joints or other anchor attachment mechanisms could be easily secured at any desired location on this bottom plate. To reduce roughness effects and minimize drag, each model was then painted with several coats of varnish.

The analytical model had previously shown that an ellipse with a major-to-minor axis ratio of approximately 2:1 would have less drag than

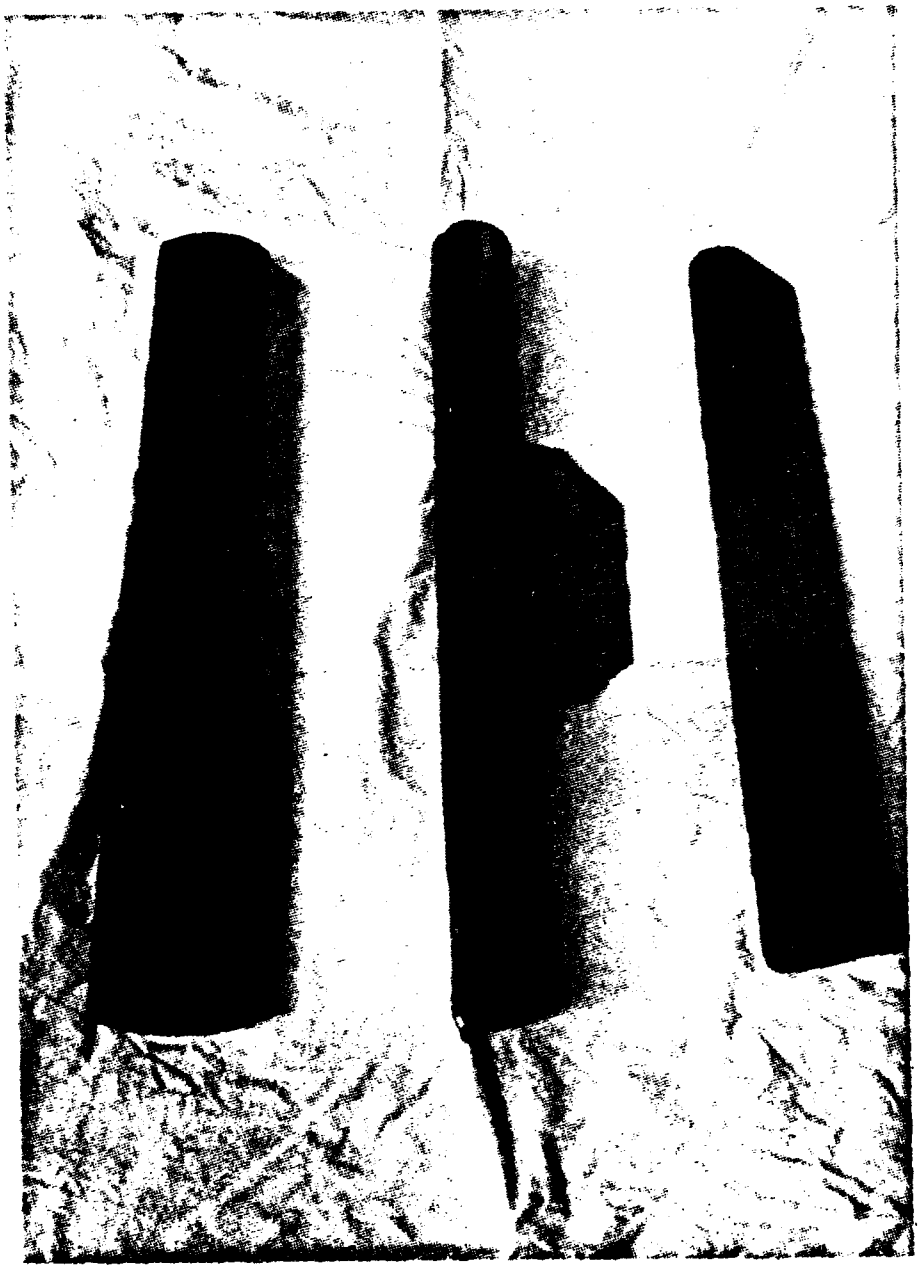


Figure III-1

The Three Buoy Shapes Used in the Circulating Water Channel Tests

a circular cylinder of the same cross-sectional area and yet be less affected by off-axis flows than ellipses with larger axis ratios. Consequently, the first model which was constructed had a major axis length of 4 inches (10.16 cm.) and a minor axis length of 2 inches (5.08 cm.) as shown in Figure III-2A. Such dimensions were selected to approximate a one-third scale model of the prototype articulated spar. In order that each shape have the same buoyancy per unit length, the subsequent prototype shapes were constructed so that their cross-sectional area was the same as that of the elliptical spar. By selecting a spar's dimensions in this manner, the shape with the smallest list angle in a given current would be the one with the least drag and consequently the most desirable for field test purposes. By comparison, the circular cross-sectioned spar had a diameter of 2.83 inches (7.19 cm.) as shown in Figure III-2B. After some initial testing, a third spar with a cone shaped cross-section was constructed and tested. This shape had a chord length of 4.60 inches (11.68 cm.) which was exactly twice its maximum width of 2.30 inches (5.84 cm.). This spar configuration is shown in Figure III-2C. To accommodate the 2 feet (0.61 m.) water depth of the channel, all of the spar shapes were built to a length of 2 1/2 feet (76.20 cm.). Since the full scale prototype was expected to be considerably greater than 3 times this length (7 1/2 feet) [2.29 m.], geometric similarity between these models and the field prototype was not fully maintained. This was not considered significant, however, because the models were constructed primarily to determine an optimized spar cross-section and as such their overall length was of secondary importance.

In comparison with the pressure drag forces acting on the spar, however, the wave-making forces created by the spar's piercing the surface were minimal and consequently all velocity scaling considerations were

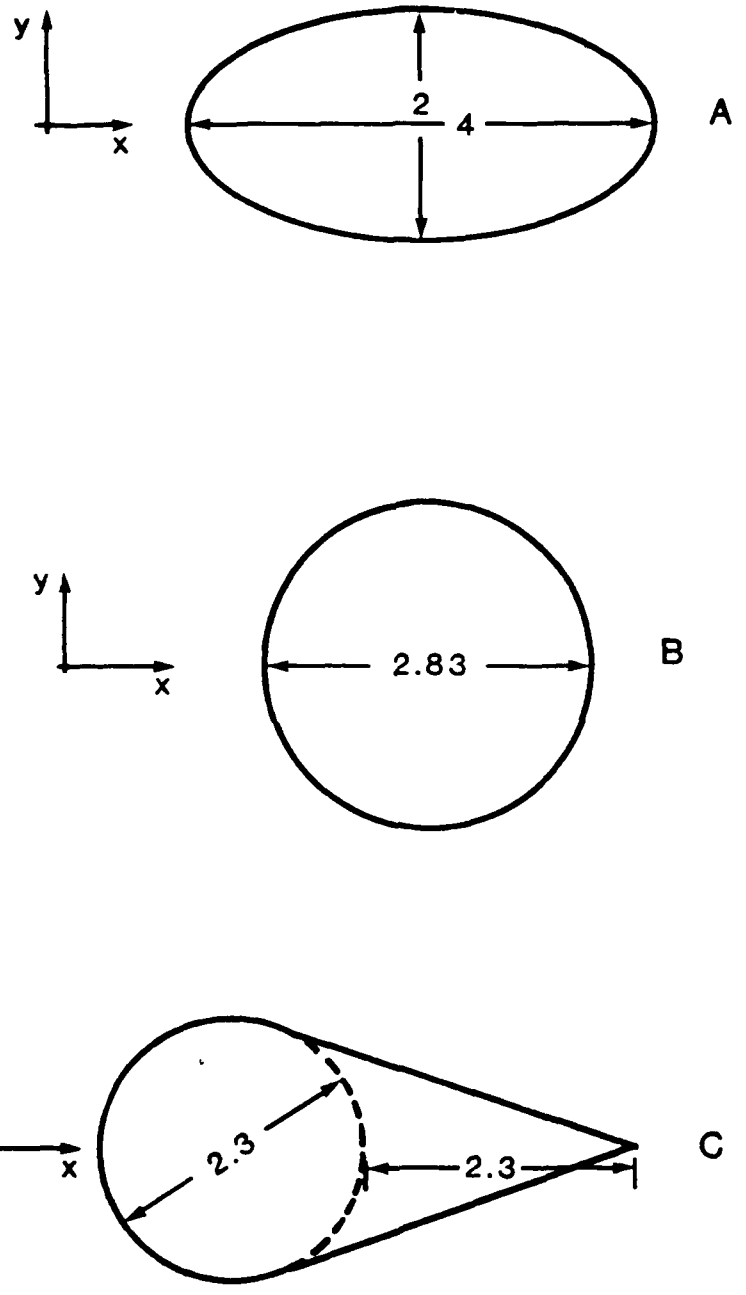


FIGURE III-2 SCALE DRAWINGS OF THE THREE PROTOTYPE SPAR CROSS-SECTIONS

based upon the Reynolds number rather than the Froude and/or Weber numbers.

III-4 Results

The initial testing was done using only the elliptical and circular cross-sectioned spars. Initial tests with the circular spar showed that at any significant velocity it would oscillate in a direction transverse to the current flow. This type of motion is the result of vortex shedding and is well documented in the literature (Blevins, 1977). The period of this oscillation was measured and generally found to be in good agreement with that predicted by empirical formulations based on the Strouhal number. The Strouhal number is generally considered to be a function of the Reynold's number although for values between 1.0×10^5 and 3.0×10^6, there is a large degree of spread in the data (Blevins, 1978). In the 1.0×10^4 to 8.8×10^4 Reynold's number range of these tests, however, the Strouhal number may be considered constant having a value of 0.19.

Some rather unexpected results were observed when the elliptical cylinder was placed in the circulating water channel. It was anticipated that this elliptical shape when anchored from a point near its leading edge would align itself such that its major axis was parallel to the direction of the current flow. In this orientation, an ellipse would present a very small projected area and consequently the drag force on the spar would be minimized. Unfortunately, however, using this elliptical prototype it was found that regardless of the location of the anchoring point on the bottom face of the spar, this shape would not align itself in the desired direction. Instead, when placed in a current the elliptical spar would immediately rotate so that its major axis was

perpendicular to the direction of flow. Once aligned in this position, the ellipse would then oscillate transverse to the flow because of vortex shedding. Milne-Thomson (1938) has shown that an ellipse free to pivot about its geometric center will rotate until the two stagnation points at either end of the major axis of the ellipse lie on a line passing through the center of the ellipse. Therefore, a spar mounted in this manner would be expected to orient itself broadside to the flow direction. However, this elliptical spar was attached to the bottom very near its leading edge, thereby greatly reducing the magnitude of the couple which would tend to rotate the buoy model.

Several possible causes for the lack of directional stability in this elliptical spar were considered. The anchor attachment mechanism used in these initial tests consisted of crudely fabricated pieces of aluminum which in principle allowed the buoy to list along its major axis and to rotate freely about its vertical axis. Since speculation as to the reason for this unusual behavior initially centered around this attachment device, a more precise mechanism; a small ball joint, was obtained and used in all future testing. Even with this device secured on the bottom face of the spar at its leading edge, the elliptical spar turned broadside to the current. Having eliminated the anchor attachment device from suspicion, other possible reasons were considered to explain the spar's unexpected behavior. It was hypothesized or deduced that compared with an airplane wing or other fixed airfoil shape, the additional degrees of freedom of this system were responsible for its lack of directional stability. Consequently, either a perturbation in the flow, a discontinuity in the actual shape of the spar, a slight offset in the anchor attachment point to either the left or right of the centerline or some combination of these possibilities caused the initial turning of the

spar in one direction. Once this turning began, there was a shift in the stagnation points and a differential pressure force which caused a net lift force to begin to act on the ellipse. This lift force would continue to increase until stall was reached. However, the spar would continue to rotate in oppositon to the increasing drag force until such time as the stagnation points were on a line which passed through the point of rotation. This stable condition would thus occur when the spar was broadside to the current.

Having concluded that the spar alone would not orient itself in the desired manner, a vane made of sheet aluminum was attached to the trailing edge of the spar in an attempt to obtain directional stability. Because of the problem of attaching the aluminum to the foam material of the buoy, an exceedingly large vane, some 24 inches (60.96 cm.) in width and spanning the entire length of the spar was tried initially. In subsequent tests the vane was shortened by cutting from the trailing edge what was deemed to be excess. The results of this series of experiments, also performed with the anchor attachment point being located on the bottom face of the spar at its leading edge, showed that for vane widths greater than 8 inches (20.32 cm.) (i.e., twice the buoy's major axis) the desired effect of having the major axis of the ellipse align itself parallel to the direction of flow of the current was achieved. Even with these large vanes, however, the spar was found to be very sensitive to slight perturbations in the trailing edge of the vane. Any small change in this trailing edge would lead to the entire spar assuming a list angle which was transverse to the flow. However, such vane widths being at least twice the length of the major axis of the spar were considered to be excessive and thus this design was excluded from further consideration.

As the vane width was shortened to less than 8 inches (20.32 cm.), the overall shape of the spar with a blunt leading edge and a sharp trailing edge began to resemble that of a wing section. The consequence of this reduction was that the spar became increasingly sensitive to very slight perturbations in the flow. Once this perturbation occurred, greater lift would develop on one side of the spar and the entire spar, while maintaining its orientation to the flow, would assume a large transverse list angle (Y axis) resulting in the spar being completely submerged. While it was at times possible to adjust the orienting vane so that the lift forces on either side of the spar were nearly equal as shown in Fig. III-3, any slight deflection of either the flow in front of the spar or of the spar itself resulted in an unstable condition from which the spar never recovered.

Three possible mechanisms to reduce this lift force and consequently improve the stability of the spar vane system were tried using a vane 4 inches (10.16 cm.) in width. In the first, a hairy fairing was added to the trailing edge of the vane. With this device no notable improvement in system stability was observed. The second method consisted of making a series of horizontal cuts about 3/4 inches (1.91 cm.) deep at a spacing of approximately 1 inch (2.54 cm.) all along the trailing edge of the vane. By bending these resulting tabs in alternating directions, a flairing of the trailing edge was accomplished. This vane modification improved directional stability somewhat but not without greatly increasing the drag force and the resulting list angle as well. Furthermore, it was found that only slight changes in these tabs, especially those located near the water surface, could drastically change the buoy's stability. Since any vessel which struck such a spar would be likely to alter these trim tabs, especially those near the water surface, this idea

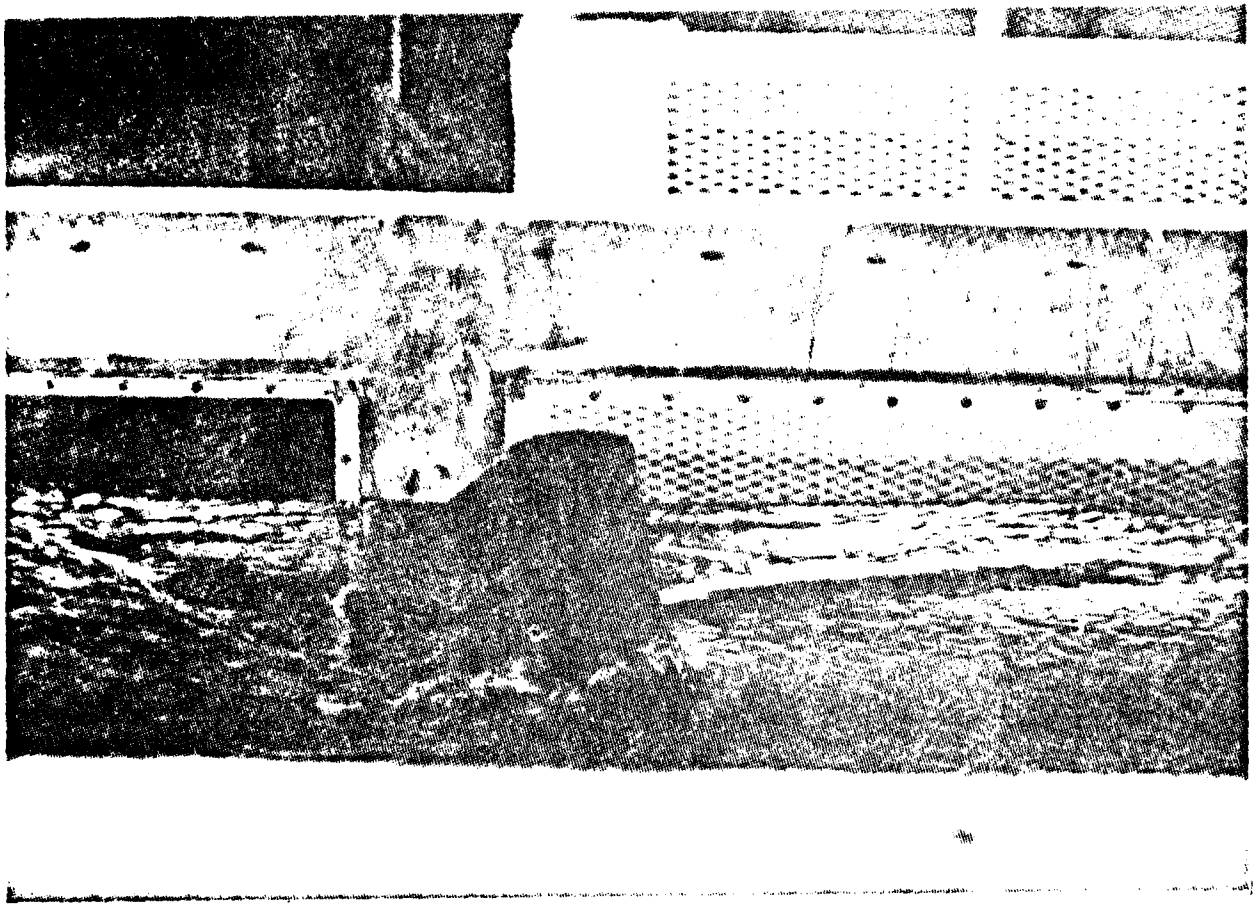


Figure III-3

The Elliptical Spar Being Tested in the Circulating Water Channel

was eliminated from further consideration. The placement of a series of holes drilled in the vane near its trailing edge did appear to reduce the magnitude of the lift force somewhat, and consequently increased the spar's stability. Unfortunately however, no way was found to either significantly reduce or stabilize the effect of this lift force.

Measurements of the list angle of this elliptical spar with a vane attached were taken when the system was in a stable mode. These measured values were found to be in good agreement with the previously developed analytical model. However, the analytical model (Chapter II) did not address directional stability criteria and, therefore, these circulating water channel tests were essential to demonstrate that while an elliptical spar does have a low drag shape, directional stability problems preclude its use without a more in depth study of appropriate orienting vanes.

Since the ellipse which had been under study had a major to minor axis ratio of 2:1 and ellipses of larger ratios would produce even greater amounts of lift efforts to determine a stable spar focused on the circular cross-sectioned spar. The oscillatory motion due to vortex shedding had been previously observed and its frequency found to correspond with that predicted by the Strouhal number; $f = \frac{S\vec{v}}{D}$.

It is well known that one of the most common ways to suppress this shedding motion is through the use of a splitter plate or vane which acts to inhibit the formation of an oscillating pressure field. Consequently, one of these plates was fashioned from a sheet of aluminum and attached to the circular cross-sectioned spar. When placed in the circulating water channel, this spar-splitter plate combination not only aligned with the flow very quickly but also proved to be very stable. Even when physically displaced from its equilibrium position, the spar quickly

returned to its original position.

Having met with this success, a number of different splitter plate sizes and shapes were investigated to determine the minimum size vane which would ensure the stability of the structure. This minimum size was found to be about 1.25 diameters, or 3.5 inches (8.89 cm.) in width, and approximately 10.5 inches (26.67 cm.) in length (or 45% of the still water submerged length of the spar). Figure III-4 is a photograph of this design being tested in the circulating water channel at a velocity of 2.5 ft./sec (0.76 m./sec.). This photograph shows the vane located near the center of the overall length of the spar. Later experimentation found greater directional stability, as determined by the rate at which the spar returned to an equilibrium position once deflected, could be achieved by locating the vane closer to the top of the spar. While the optimum location of this splitter plate relative to the water depth varies with the current velocity, the closer the top of the vane is to the water surface without protruding above it, the better. In this location, the splitter plate suppresses the oscillating lift force which would, if present, produce the largest overturning moment on the spar.

Having determined the minimum size splitter plate necessary to maintain the stability of the spar structure, numerous measurements of the current velocity and the corresponding list angle were made. This data presented in Table III-1 was then compared with that predicted by the analytical model. The results of this comparison are shown in Figure III-5. This figure shows generally good agreement between the observed and predicted results. At low current velocities, the theoretical model appears to overpredict the list angle, most likely because of the conservative nature of the 1.2 drag coefficient value used in the list angle determination. At these low velocities and correspondingly small list

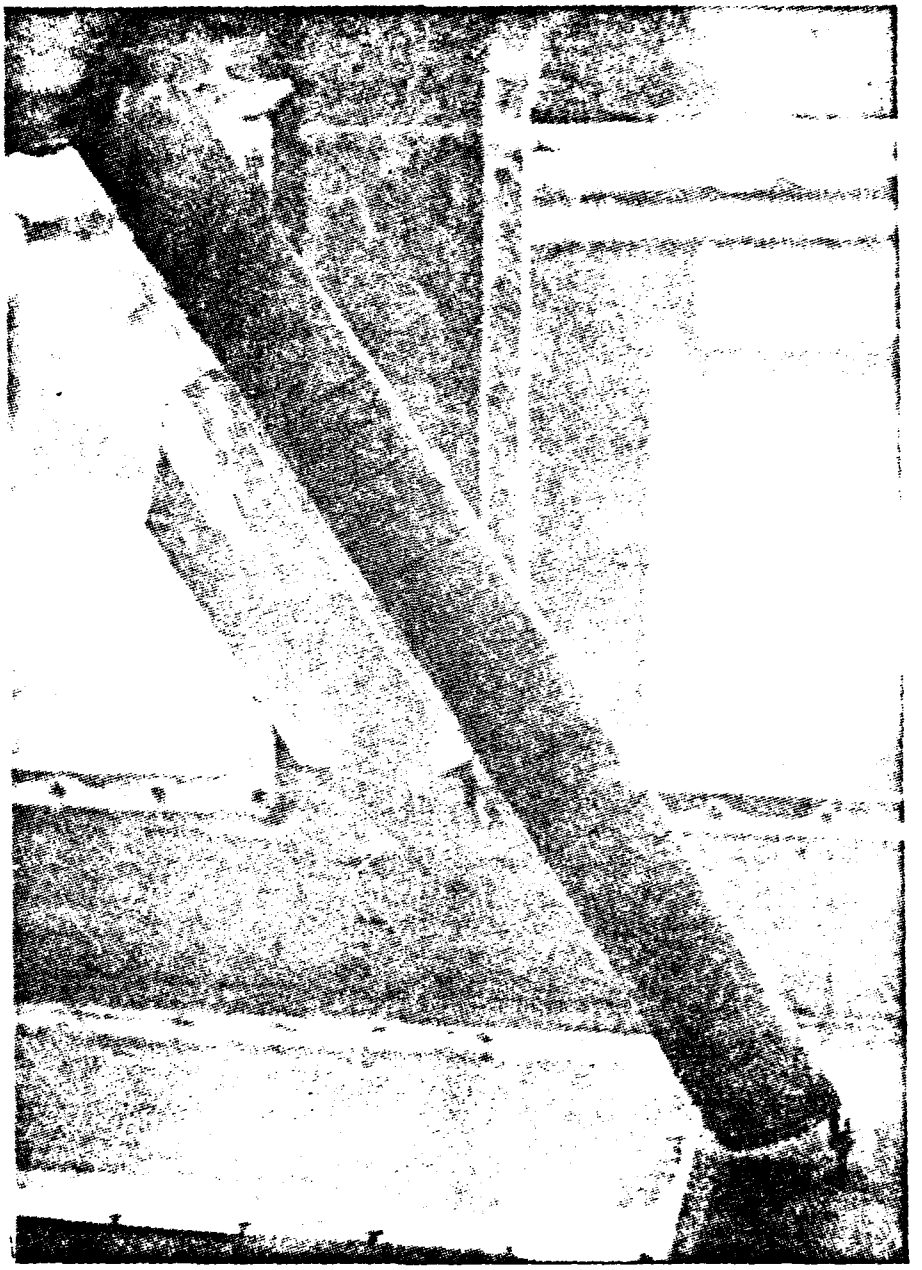


Figure III-4

The Circular Spar in the Circulating Water Channel with a Splitter Plate

TABLE III-1

LIST ANGLE DATA FOR A 2.83 INCH (7.19 cm.) DIAMETER SPAR, 30 INCHES (76.20 cm) IN LENGTH WITH A SPLITTER PLATE

Velocity (FT./SEC.)	[cm./sec.]	MEASURED LIST ANGLE (DEGREES)	ESTIMATED ERROR (DEGREES)
0.00	[0.00]	-3.5	$\pm$0.5^{o}
0.50	[15.24]	-1.0	$\pm$0.5^{o}
1.00	[30.48]	3.0	$\pm$1.0^{o}
1.50	[45.72]	11.0	$\pm$1.5^{o}
2.00	[60.96]	20.0	$\pm$1.5^{o}
2.50	[76.20]	28.0	$\pm$2.0^{o}
3.00	[91.44]	34.0	$\pm$2.5^{o}
3.50	[106.68]	39.0	$\pm$3.0^{o}

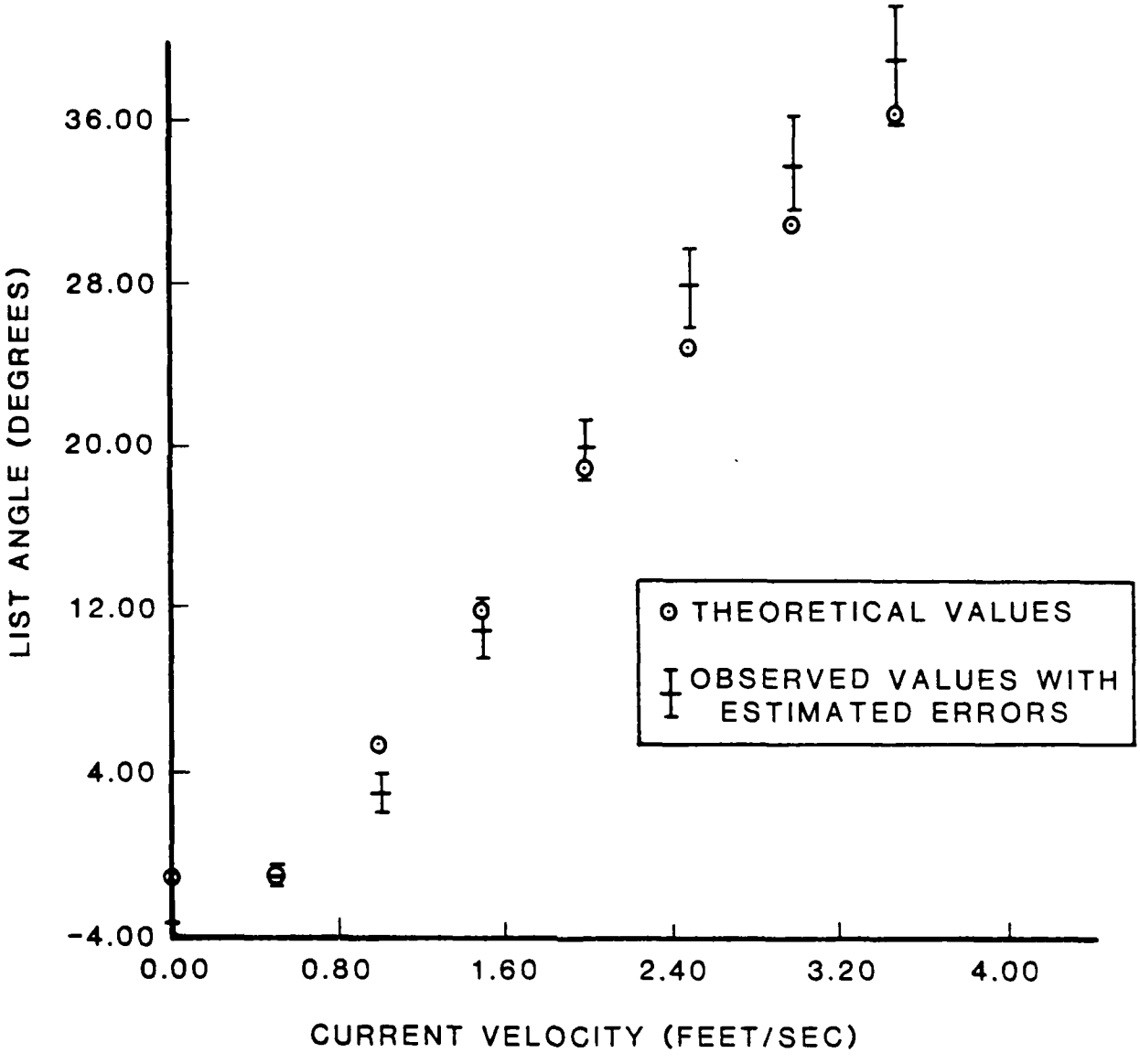


FIGURE III-5 CIRCULATING WATER CHANNEL. THEORETICAL AND OBSERVED LIST ANGLES FOR A CIRCULAR CYLINDER

WPL/BPL = 0.094

L/h = 1.25

angles, the length-to-diameter ratio of the spar may be of importance, thus indicating the use of a smaller drag coefficient as outlined in Chapter II. At higher velocities and consequently greater list angles, this L/D ratio is of doubtful importance. However, at these higher velocities, the surface roughness of the spar may become significant. The effect of such roughness elements is to increase the drag coefficient and consequently the resulting list angle would be greater than that predicted by theory.

III-5 Additional Testing Results

In an effort to find another design which had the stability characteristics of the circular cylinder with a small splitter plate attached yet having a smaller drag coefficient, a third buoy shape was constructed and tested. When a fluid moves past a cylinder with a splitter plate, two identical Foppl vortices form on either side of the plate in the region near where it joins the cylinder. The location of these vortices is shown in Figure III-6. Once formed, these vortices remain stationary and, therefore, by filling in these areas with some material and thus eliminating them altogether, it was postulated that another stable buoy configuration would result. The resulting buoy had a conical shaped cross-section as shown in Figure III-2C. While this streamlined shape does have a smaller drag coefficient than a cylinder of the same projected area, tests performed on this **shape** showed that it was unstable as it sailed back and forth transverse to the flow. Efforts at suppressing this sailing motion met with only limited success. A hairy fairing attached to the trailing edge of this conical shaped device proved to be the most successful, but was only able to reduce the frequency of the sailing motion by approximately 50%.

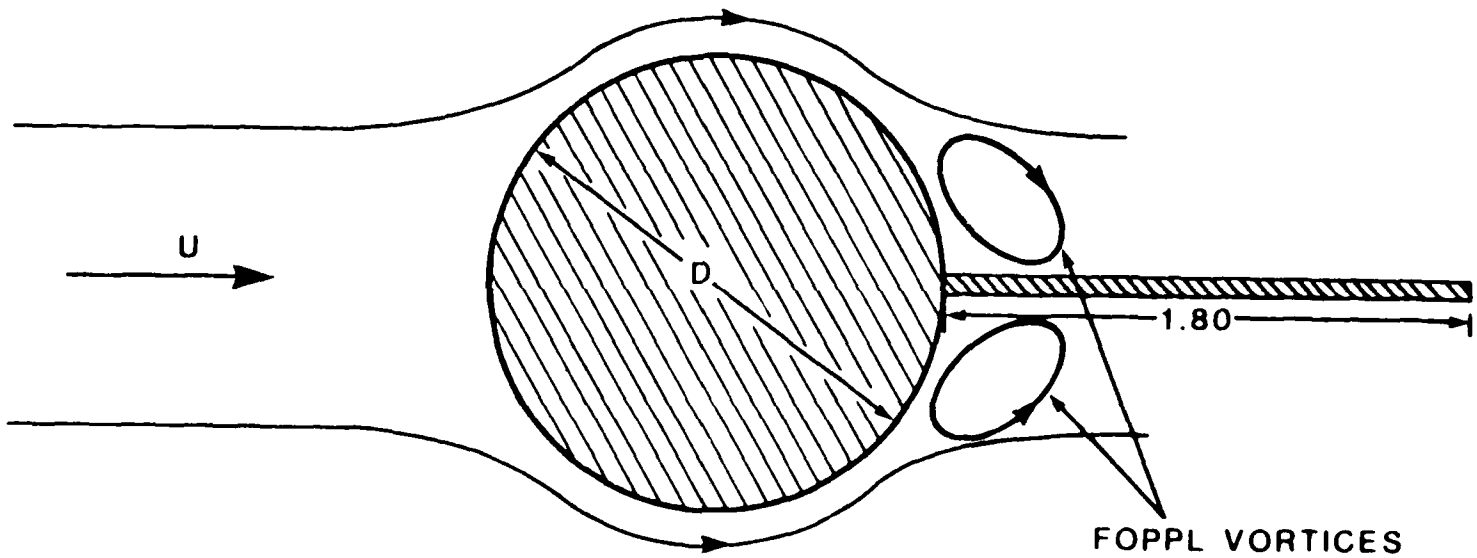


FIGURE III-6 FOPPL VORTICES FORMED BEHIND A CIRCULAR CYLINDER WITH A SPLITTER PLATE

III-6 Field Model Selection

The results of this series of laboratory tank tests demonstrated that only a cylinder with a circular cross-section and a splitter plate was directionally stable and would return to an equilibrium position when temporarily displaced. In addition, generally good agreement was found between the measured list angle of this spar section and that predicted by the analytical model. Consequently this shape was chosen for the field testing phase of this validation study.

CHAPTER IV

THE FIELD TEST

IV-1 Spar Description

A full scale spar prototype was constructed for the purpose of validating the analytical model under actual field conditions. The actual spar was constructed from 18 feet (5.49 m.) of 6 inch (15.95 cm.) diameter schedule 40, T6061 aluminum pipe. In addition to this pipe, two end caps, a mooring attachment device and a vane attachment guide were fabricated and then welded to the spar section. Drawings used in the construction of this field prototype are presented in Appendix III. While it is recognized that a spar of these dimensions is quite small in comparison with standard government aids, weighing about 130 pounds (59.1 kg.), this spar represented the most practical design which could be easily transported and deployed without mechanical assistance. Fabrication of this articulated spar was performed by the Durant Machine Company of Noank, Connecticut.

Once fabricated, a vane constructed from 1/2 inch (1.27 cm.) plywood was bolted to the vane attachment guide. This vane measured 11.72 feet (3.57 m.) in length and 10.5 inches (26.67 cm.) in width and was situated so that the bottom edge of the vane was 4 feet above the mooring attachment point. The ratio of the width of this vane to the diameter of the spar was about 1.58, which was slightly larger than the minimum 1.25 value determined in the circulating water channel tests. The reason for this slight increase was to provide some margin of safety in assuring that the spar would perform as expected.

Once the vane was attached, the spar was painted with 8 inch (20.32 cm.) alternating orange and white bands. Figure IV-1 is a photograph of

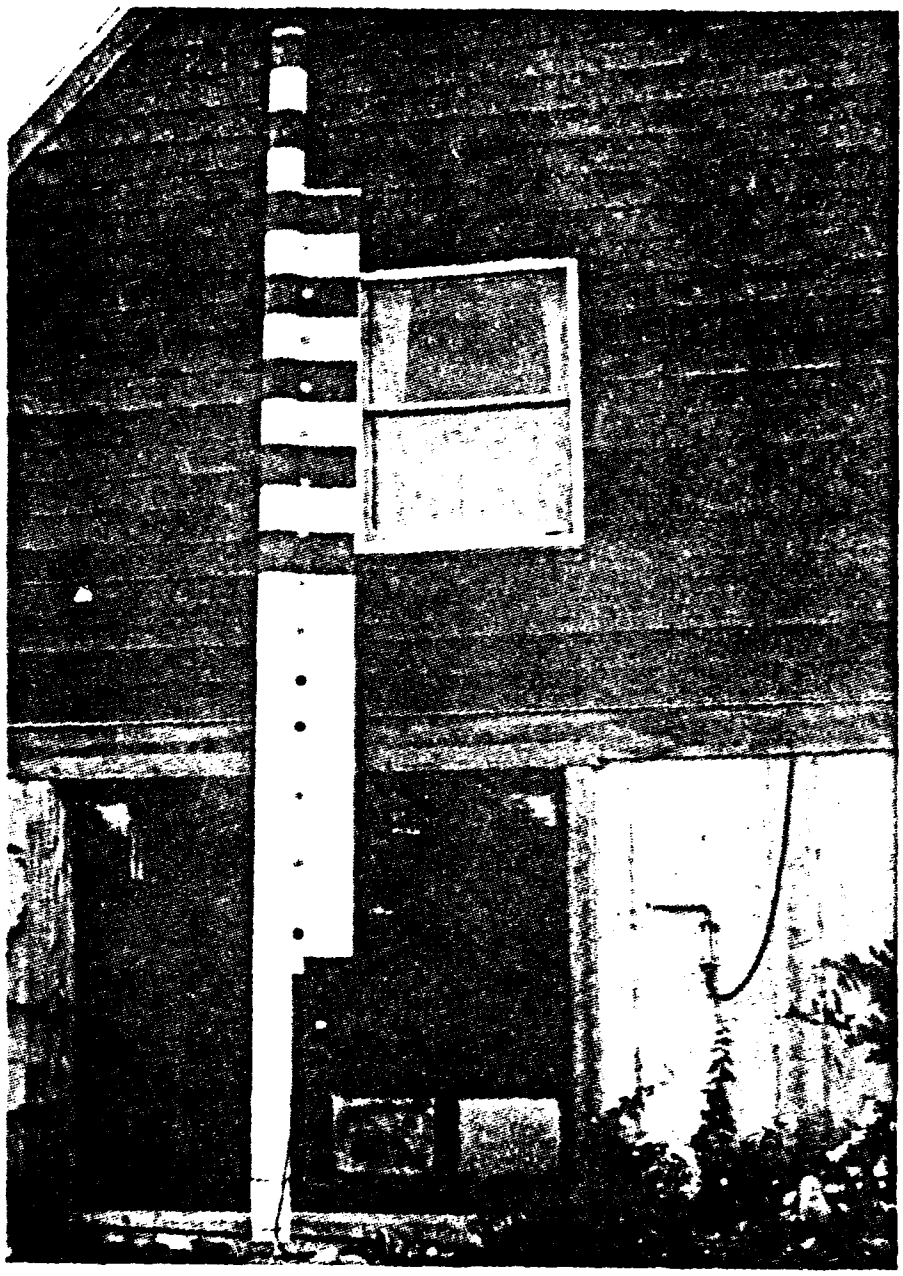


Figure IV-1

The Field Prototype Articulated Spar Buoy

the completed spar device. During the actual deployment a quick flashing white light was mounted on top of the spar as an additional safety precaution.

A swivel joint served to connect the spar to its mooring. This swivel could be attached in any one of three locations along the bottom of the spar depending upon the desired angle of list at slack current. this attachment swivel and the three possible holes are shown in Figure IV-2.

The anchor used in these tests consisted of four 100 pound (45.45 kg.) lead blocks placed in a box as shown in Figure IV-3. When initially deployed, each of these four blocks was individually placed in the box, after which the spar was attached to the iron eye at the center of the box.

IV-2 Siting Considerations

In order to test this spar, an area with a relatively high current and shallow water near the University of Rhode Island was required. Point Judith Pond, a large coastal pond located along the southern shoreline of Rhode Island was selected for the field test. It has predominately shallow water and in the vicinity of its narrow opening to the ocean, high currents. Figure IV-4 is a map of the pond showing the test site location. While currents in this pond are strongest in the entrance, safety considerations with regard to the large amount of boat traffic here precluded placing the spar in this area. The entrance channel coming into the pond separates into two sections just north of the narrow entrance. The banks of the much less traveled right hand fork of the channel is occupied by numerous waterfront cottages and the Department of Environmental Management's Marine Experiment Station. At

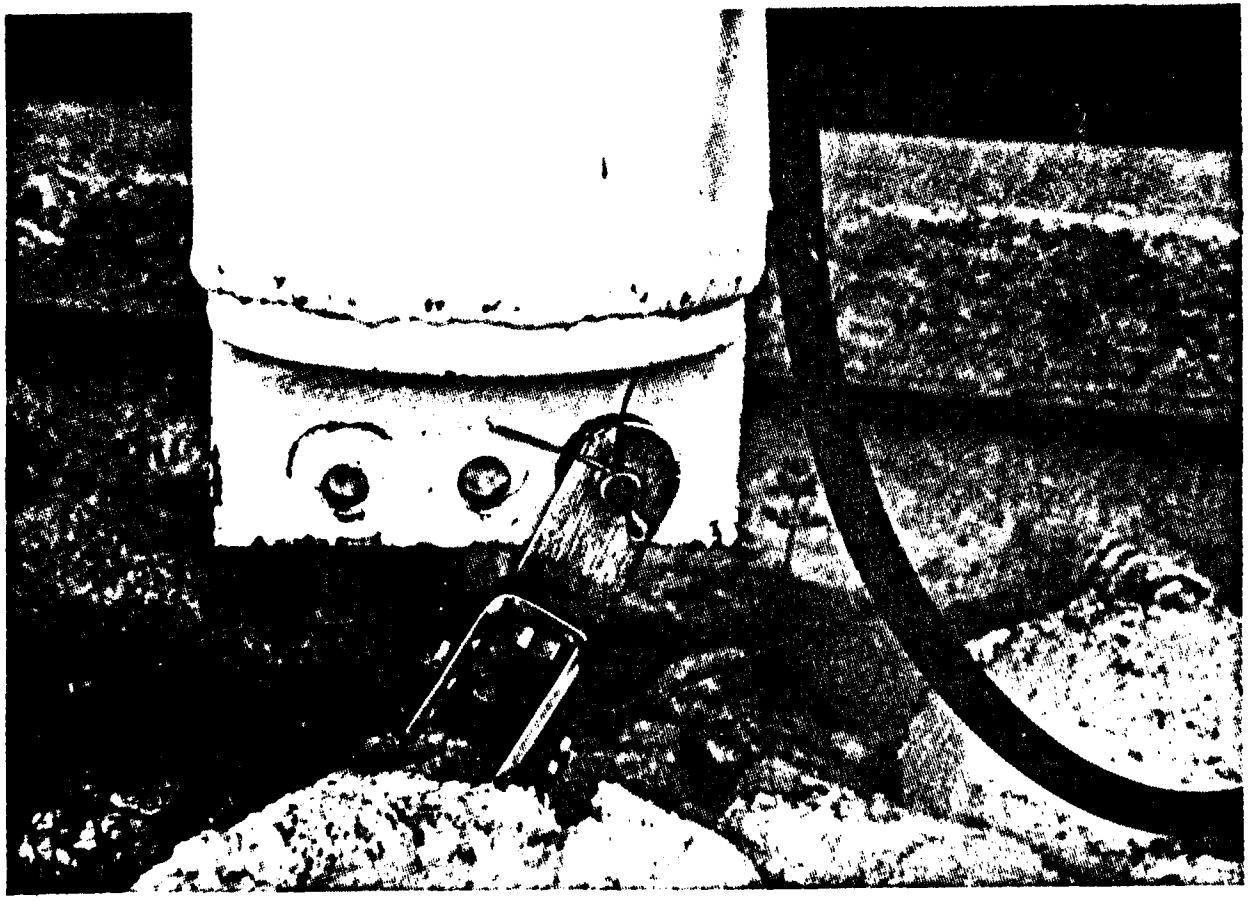


Figure IV-2

The Field Prototype Anchor Attachment Point

Figure IV-3

The Anchor Used for Testing the Field Prototype

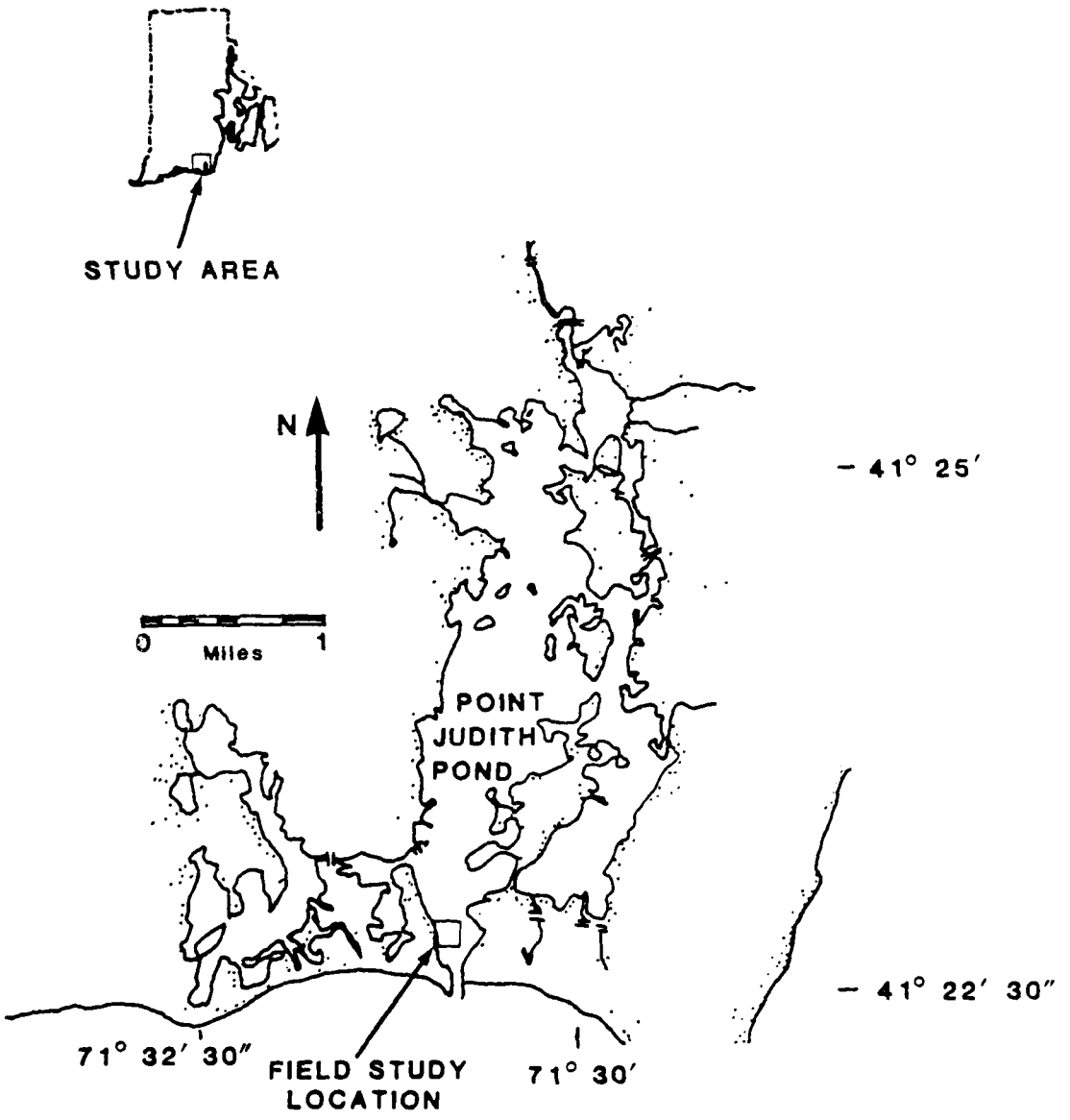


FIGURE IV-4 MAP OF POINT JUDITH POND AND VICINITY

this station, two piers protrude from the shore to the edge of the channel, making an excellent observation and work platform. Further, the availability of working space for locating the instrumentation recorders, ample shore power and the cooperation and assistance of the employees of the Department of Environmental Management made this site a most logical selection from which to perform the field test. The widtn of the channel at this location is very narrow being only about 200 ft. (60.96 m.) wide, and consequently, the current velocities here, while not as strong as those at the pond's opening are still as large as 2.0 ft./sec. (60.96 cm./sec.).

IV-3 Data Collection

The spar was instrumented with two Humphrey's Model CP17-0601-1 inclinometers mounted orthogonally to one another on the inside portion of the upper end cap. These inclinometers shown with the end cap in Figure IV-5 were secured to the spar in such a way that the list angles parallel and perpendicular to the orienting vane and consequently the expected flow, were measured. A multi-conductor cable passing through a water-tight seal in the end cap supplied the necessary input voltage and also carried the output signal to the shore based recorders.

The inclinometers used in this field test consisted of a series of wire wound potentiometers whose resistance was controlled by the motion of a pendulum type slider. Thus by supplying a constant current at a known voltage to this inclinometer and recording the output voltage, the angle of inclination could be computed. A schematic drawing of this inclinometer system is shown in Figure IV-6. The output signal from both of these inclinometers was continuously recorded on a Hewlett-Packard

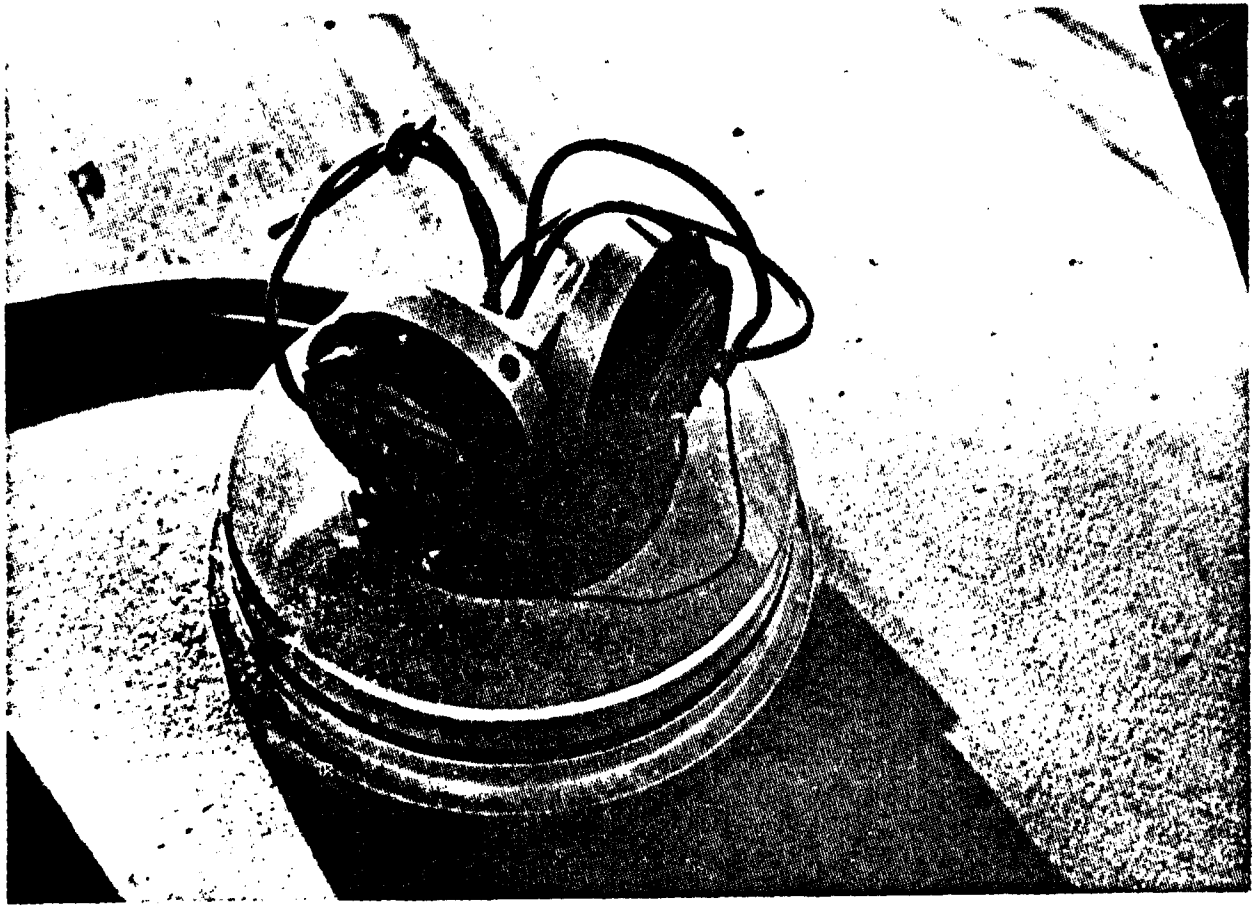
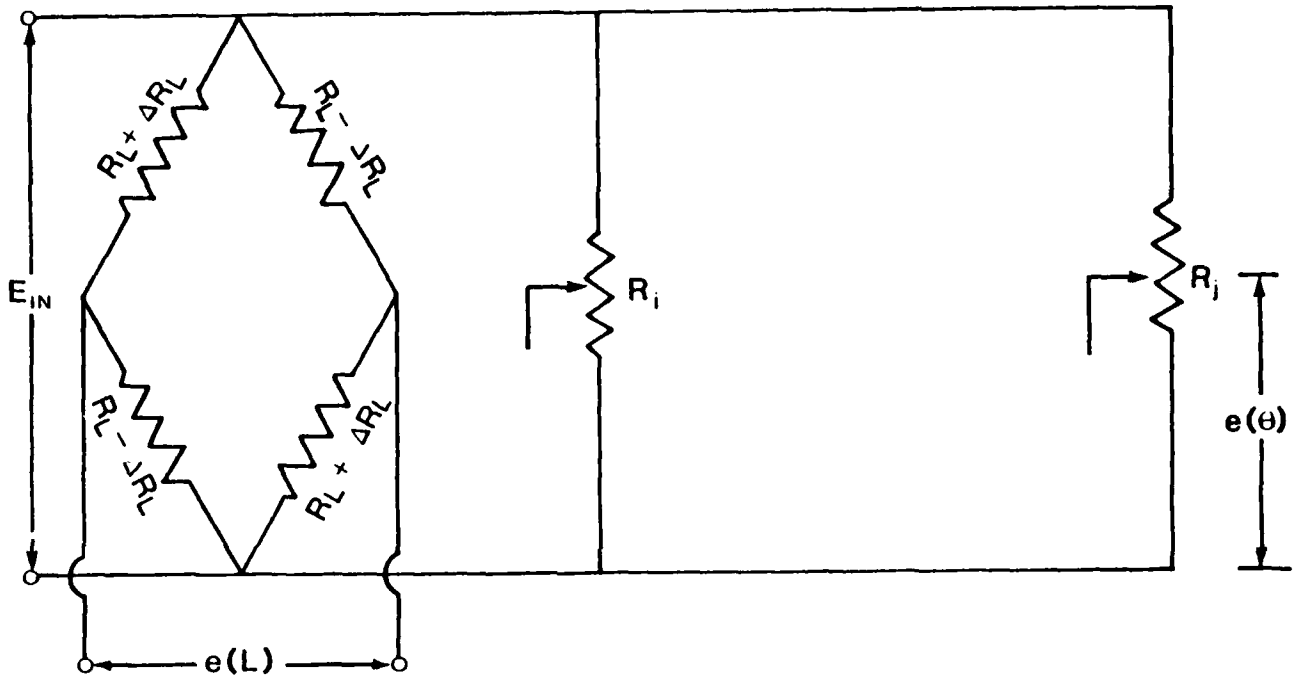


Figure IV-5

Inclinometers Used in the Field Prototype Spar Buoy



$$e(L) = \Delta R_L / R_L \; E_{IN} \quad \text{(Load Cell)}$$

$$e(\theta) = r / R_L \; E_{IN} \quad \text{(Inclinometers)}$$

FIGURE IV-6 INCLINOMETER AND LOAD CELL WIRING DIAGRAM

Model 7100B two-pen strip chart recorder using different colored recording pens to distinguish the two output signals. The input signal was periodically monitored to ensure its consistency with a digital voltmeter.

In an effort to measure the total tangential force which the spar exerts on the mooring system, a load cell was connected between the mooring eye and the swivel at the lower end of the spar. By measuring this force and by knowing the list angles in both the X and Y directions, the total force acting on the spar could be readily computed. Furthermore, by measuring the local current velocity and knowing the resultant force, an estimation of the average drag coefficient of the spar could be made. Operating in much the same manner as the inclinometers, changes in load were detected by a pressure transmitter, changes in load were detected by a pressure transmitter which converted these signals to changes in resistance. By supplying a known voltage to this load cell and measuring its output, the force being applied could be computed as schematically shown in Figure IV-6. A separate cable was used to connect this piece of instrumentation with the necessary shore power and recording device. Output data from this load cell was recorded on a single channel Linear Instruments strip chart recorder. Like the inclinometers, the output signal from this load cell was recorded continuously and the input signal was periodically checked with the voltmeter to ensure its consistency.

Current velocity measurements in the vicinity of the articulated spar were made using a Savonius rotor-type current meter. As this current meter was equipped only with a rotor, only speed measurements were made Current direction was recorded based upon visual observation as being either ebb or flood. These current speed measurements, taken from a small boat moored immediately adjacent to the spar, were made at three different locations in the water column, near the surface, at mid-depth.

and at the bottom, to detect any vertical variation which might be present. Because of the rather large tidal range of approximately 39 inches (99.06 cm.) at this location, no attempt was made to determine the exact depths at which these current measurements were taken. Further, except for small periods of time near slack water, little or no vertical variation was found in these current profiles. Because of the time involved in making these current measurements, as well as the relative rate of change of the current speed, these readings were taken at approximately 30 minute intervals. Like many coastal ponds, a large amount of seaweed and other debris was present in the water column. Consequently the problem of fouling of the rotor precluded the use of a moored current meter.

The water depth at the spar was another parameter which was measured as part of this field test. Using a stilling well mounted on the Marine Experiment Station dock nearest the spar, relative tidal height changes were obtained. By measuring the depth at the spar and simultaneously recording the stilling well reading, a correlation between other stilling well observations and the water depth at the spar could be made. Because of the large tidal range at this location, stilling well observations were made approximately every 20 minutes to ensure accuracy.

IV-4 Results

IV-4.1 Configuration #1

Data from this field test was accumulated over the period 21 May to 24 May 1979. Initially the spar configuration and data collection procedure described above were used and those results are presented below as Table IV-1. The time recorded in this table has as its origin 00:00 on the 21st of May. Cursory examination of this data indicates that the

TABLE IV-1

CONFIGURATION # 1 FIELD DATA

TIME (HOURS)	VELOCITY (FT./SEC.)	DEPTH (FEET)	MEASURED * LIST ANGLE (DEGREES)
16.50	0.34	11.68	32.6
17.00	0.10	11.91	31.7
17.50	0.56	11.90	32.6
18.00	0.39	11.77	33.5
18.62	0.39	11.48	37.1
23.50	0.81	8.39	50
24.20	0.25	8.35	---
24.83	0.03	8.50	---
25.50	0.79	8.78	50
26.12	0.64	9.46	48
26.75	0.57	9.75	43
27.33	0.17	10.25	42
27.75	0.56	10.57	40
28.42	0.03	11.04	35
29.00	0.32	11.33	31
29.52	0.01	11.48	30
30.00	0.34	11.42	33
30.67	0.68	11.16	33
31.17	0.81	10.89	35
31.58	1.00	10.58	35
32.17	1.52	10.07	42
33.00	1.69	9.38	47
33 58	1.69	8.85	50
34.17	1.40	8.46	50
34.83	1.42	8.25	52
36.05	0.32	8.13	50
36.50	0.64	8.21	55

* Whole number values from hand inclinometer

magnitude of the list angle of the spar in this configuration was quite large with values ranging in size from 31.7° to 55°. Since the inclinometers mounted in the spar were only capable of resolving angles up to 45°, much of the inclination data presented in this table was obtained from hand inclinometer/protractor measurement. To differentiate between those inclinometer values obtained from the internal inclinometers and those measured with the hand held inclinometer/protractor, values fitting into the latter category are listed as whole numbers in Table IV-1. Figure IV-7 is a photograph of the spar in this first configuration. It is apparent from this figure that a great deal of the spar's 18 feet (5.49 m.) of length is above the water surface thereby explaining the large list angle values. In addition, this photograph shows the spar oriented with the splitter plate directed into the current. Observations of this unexpected behavior revealed that it only occurred at very low velocities, generally less than 0.25 ft./sec. (7.62 cm./sec.). At velocities greater than this threshold value, the vane would turn so that it was no longer oriented into the current but at some angle. As the velocity continued to increase, the spar would continue to rotate until the vane was situated downstream and parallel to the flow at velocities of 0.4 ft./sec. (12.19 cm./sec.) or greater. It was initially suspected that this unusual orientation at low velocities was the result of the buoyancy of the vane material. However, subsequent analysis of this behavior revealed that the off-center mooring attachment point was the cause. In this first configuration, the spar was anchored by the forward most of the three anchor attachment holes (i.e., the hole furthest from the vane).

After observing the behavior of the spar in this configuration for approximately two tidal cycles, several facts became evident. Because of

Figure IV-7

The Field Articulated Spar Anchored in Configuration #1

the shallow water depth there were periods of time in which the water depth was less than half of the total spar length. Consequently, with so much weight in the air, large list angles were encountered.

This experiment was extremely useful in that the effects of spar submergence compared to spar length became readily apparent. It was concluded that in any future tests the total spar should be shortened. Since the load cell, which is 27 inches (68.58 cm.) in length, had not provided useful data during this test, it was decided to remove it in future field tests.

IV-4.2 Configuration #2

In the second configuration, the load cell was removed, effectively decreasing the spar length-to-water depth ratio, and the mooring attachment point was shifted to the aftermost of the three attachment holes (i.e., the hole nearest the vane) to prevent any reverse orientation of the spar at low velocities. A photograph of the spar in this new configuration is shown in Figure IV-8. Data obtained from the spar in this configuration is presented in Table IV-2. In addition to the list angle values measured by the inclinometer, this table also included corresponding output from the analytical model. Comparison of these two sets of values, however, can only be made following an analysis of the errors inherent in these field data measurements as summarized in Table IV-3.

Slight variations in the actual wind and current profiles as well as vibrations in the spar contributed to the uncertainty in the inclinometer measurements which were estimated to be $\pm$ 1.3^{o}. Current and water depth measurements were taken during this field test for use as input data to the analytical model.

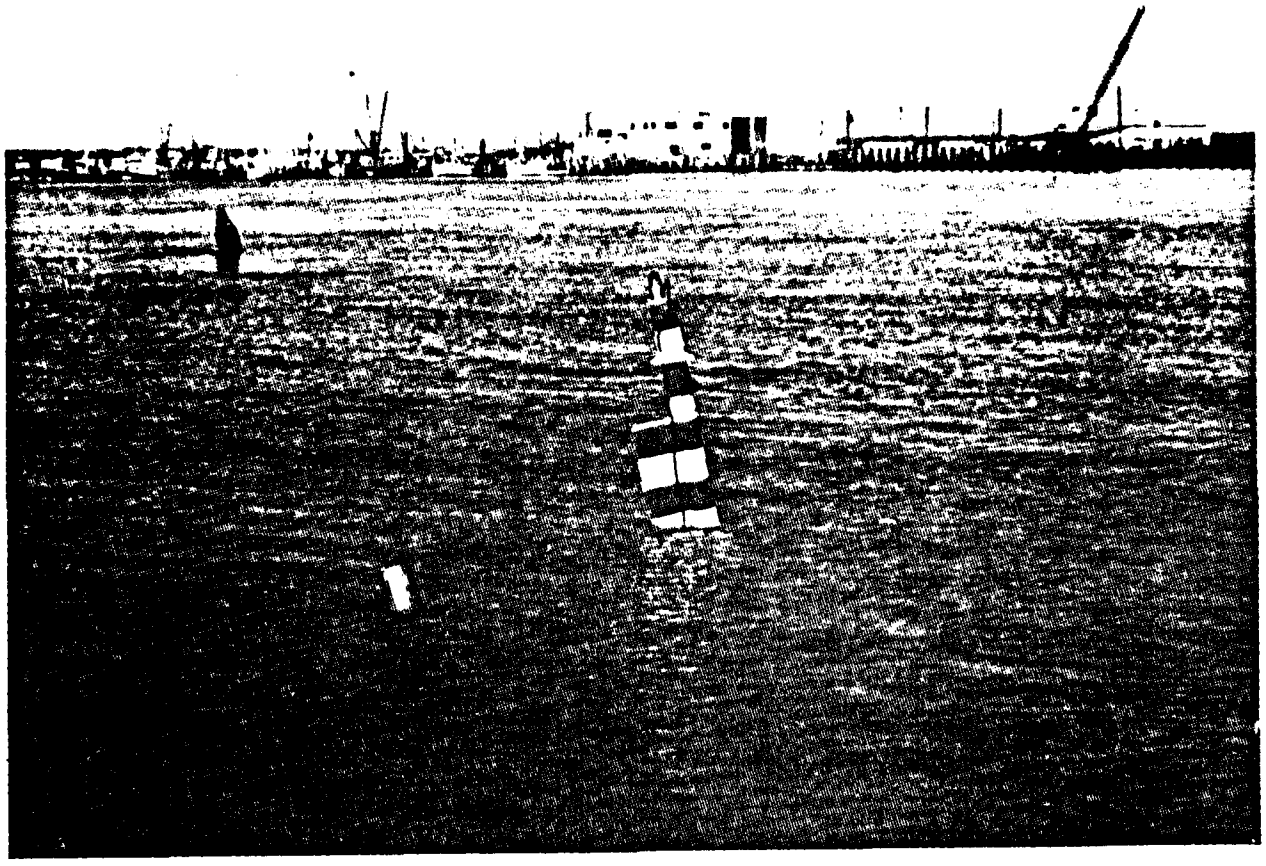


Figure IV-8

The Field Articulated Spar Anchored in Configuration #2

TABLE IV-2

CONFIGURATION # 2 FIELD DATA

VELOCITY (FT./SEC.)	DEPTH (FEET)	LIST ANGLE (DEGREES)	COMPUTED LIST ANGLE (DEGREES)
0.78	10.46	32.4	34.2
0.25	11.43	22.9	25.8
0.34	12.37	13.6	2.0
0.32	12.17	5.9	1.6
0.10	13.40	3.4	1.0
0.34	13.17	7.7	1.6
0.85	12.60	17.0	15.2
1.32	12.25	19.6	24.2
1.49	11.94	23.8	27.2
1.76	10.40	36.6	38.1
1.55	9.83	38.4	39.8
1.18	9.62	38.8	40.4
0.76	9.58	39.2	40.2
0.34	9.59	38.5	39.9
0.34	9.76	37.7	38.9
0.81	9.94	37.3	38.6
1.00	10.34	34.1	35.8
0.68	10.78	31.2	32.3
0.51	11.20	27.5	27.3
0.34	11.74	22.8	20.9
0.01	12.20	16 8	1.3
0.34	12.62	11.5	1.8
0.08	12.82	7.3	1.1
0.34	12.85	9.0	1.7
0.30	12.87	8.1	1.7
0.68	12.57	11.1	14.3
0.51	12.34	13.3	14.3
0.85	12.09	18.0	20.9
1.13	11.77	21.5	26.4
1.35	11.32	27.2	31.2
1.52	10.88	30.6	33.7
1.77	10.21	35.8	38.9
1.64	9.77	37.5	40.2
1.27	9.54	38.2	41.0
1.27	9.54	38.2	41.0
0.08	9.47	37.9	40.5
0.47	9.67	37.1	39.5
0.41	9.91	35.0	38.5
0.20	10.57	30.7	32.9

TABLE IV-3

FIELD TEST MEASUREMENT ERROPS

Variable	Estimated Error
List Angle	±1.3°
Current >10.76 cm./sec. (Threshold = 10.76 cm./sec.)	±10%
Water Depth	±7.62 cm.

A Savonius rotor, which is well known in the literature for its non-linearity, was used to determine current profiles in the vicinity of the spar. Typically these current meters have a non-zero threshold, a tendency to stall at very high speeds, and exhibit more rapid acceleration than deceleration (Beardsley, et. al., 1967). In addition tilt effects have been shown to significantly effect the accuracy of measurements made with these devices although their exact impact varies from one instrument to another as well as over various speed ranges. During the field test, however, it was observed that at low velocities (less than 0.35 ft./sec. (10.67 cm./sec.)) the current meter readings were subject to large fluctuations resulting from the inability of the magnetic reed switches in the current meter to function properly. Consequently, the errors associated with these low velocity measurements were extremely large and, therefore, such values were omitted from further study. Current values greater than 0.35 ft./sec. (10.67 cm./sec.) were estimated to be accurate to within $\pm$ 10%.

The water depth measurement used as an input variable to the analytical model is the distance from mean sea level to the bottom of the spar. These water depth values were estimated from stilling well observations and a single correlation measurement of the total water depth. Although the stilling well observations were virtually error-free, the total depth determination was subject to an error estimated to be $\pm$ 2 inches ($\pm$ 5.08 cm.). In addition, the distance from the base of the spar to the pond bottom was measured to an accuracy of $\pm$ 1 inch ($\pm$ 2.54 cm.). Consequently, the total error associated with these water depth measurements was $\pm$ 3 inches ($\pm$ 7.62 cm.).

A sensitivity analysis was performed to determine the significance of these current velocity and water depth uncertainties on predicting the

list angle of the spar. Assuming a ± 10% error in current values greater than 0.35 ft./sec. (10.67 cm./sec.), the change in the spar's list angle was found to be on the order of 0.1^{o} to 0.2^{o}. Consequently, for this buoy configuration, potentially large errors in the current velocity measurements did not significantly effect the spar's list angle.

Figure IV-9 shows the results of a sensitivity analysis of the effect of changes in the water depth over the range experienced in this field test on the spar's list angle assuming three separate current velocities. The relative steepness of the slope of these lines indicates that this field test spar buoy was very sensitive to slight changes in the water depth especially at low velocity values. Therefore, of the two parameters measured for use as input data to the analytical model, only errors in the water depth were found to significantly affect the spar's predicted list angle.

Figure IV-10 is a parity plot of the measured vs. computed list angle data with error bars indicating the uncertainties associated with individual water depth and inclinometer determinations. The relative variation in the width of these error bars results from absolute variations in the current velocity and water depth measurements from which these list angle values were computed. Comparison of model predictions and field measurements as noted in Figure IV-10 shows excellent agreement with a correlation coefficient of 0.986.

IV-4.3 Splitter Plate Removal

As the final phase of this field test the splitter plate was removed from the spar to determine the effect such a change would have on the performance of the spar. It was expected that in stronger current situations (>0.5 knots) [>25.76 cm./sec.] that some vortex shedding motion

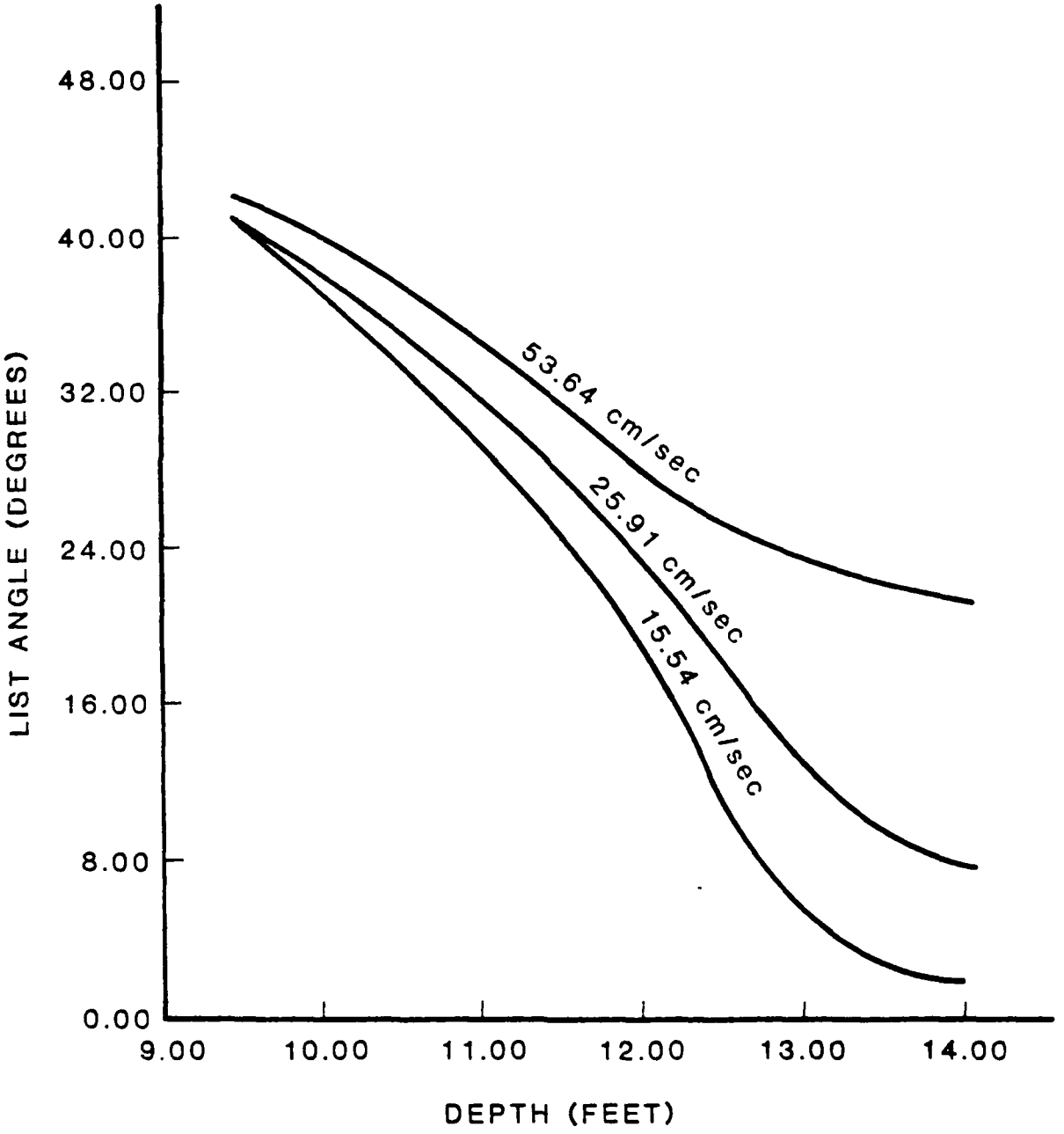


FIGURE IV-9 LIST ANGLE VS DEPTH CURVES OF THE FIELD PROTOTYPE SPAR AT VARIOUS CURRENT VELOCITIES

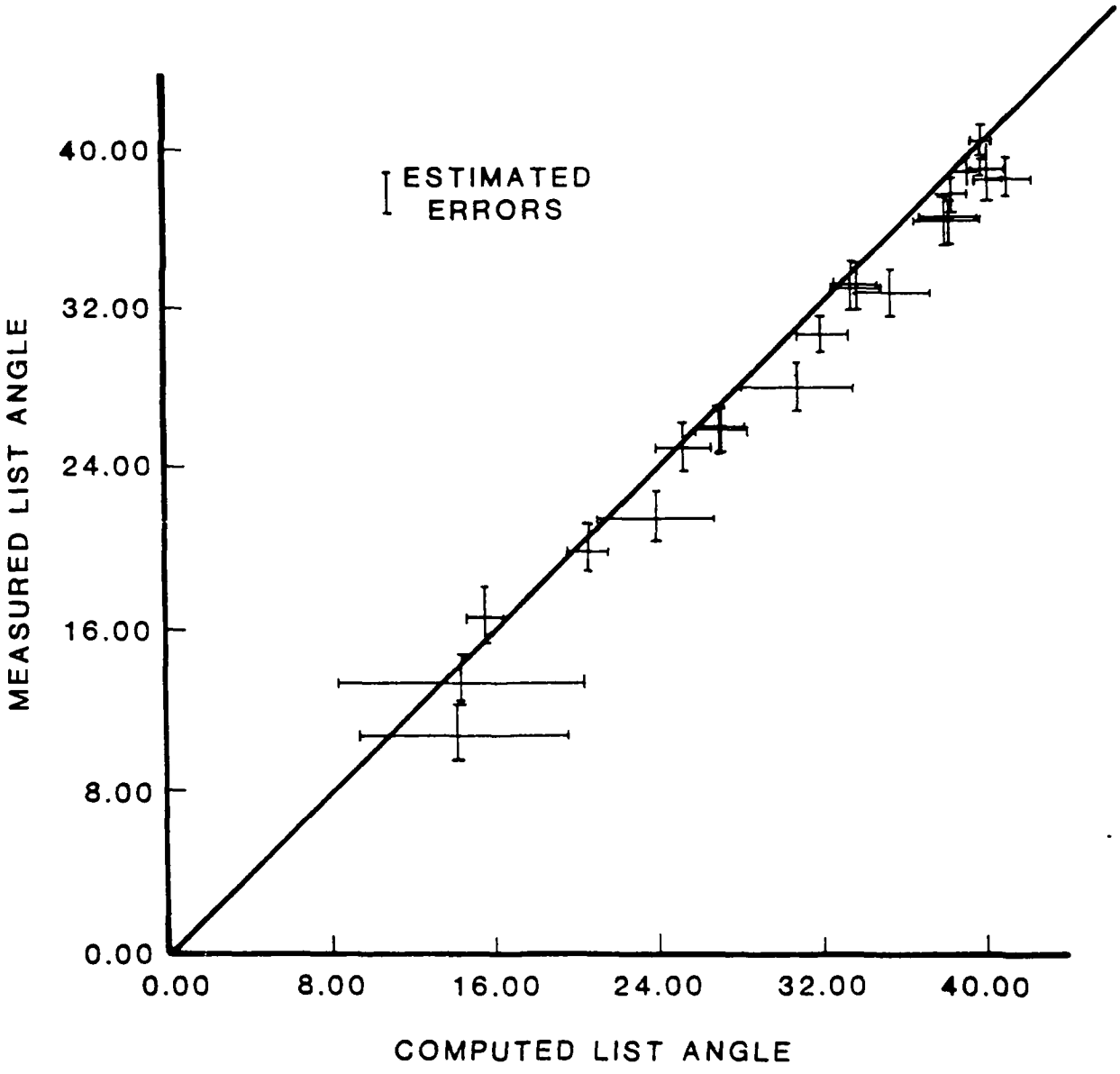


FIGURE IV-10 PARITY PLOT OF MEASURED VS COMPUTED LIST ANGLE DATA

would be observed. Equipment problems prevented the accurate determination of the spar list angle, but no unusual list angles were observed when the splitter plate was removed. However, the expected vortex shedding motion did not occur.

As was true in configuration #2, the spar was moored at the aftermost of the three mooring attachment points. It was observed that turning the spar about its vertical axis did not result in an arbitrary reorientation of the spar. Rather, the spar always tended to return to a position where the mooring attachment plate was parallel to the current. Initially, it was speculated that the welded, vane attachment point was acting as a splitter plate and thus preventing any vortex shedding motion. The hypothesis was rejected because subsequent analysis revealed that the uncentered mooring attachment resulted in a torque being placed on the spar. This torque combined with the asymmetry of the spar resulting from the vane attachment plate resulted not only in the spar orienting itself into the current, but prevented vortex shedding from occurring at these velocities by inhibiting transverse motion.

CHAPTER V

SUMMARY

V-1 Review of Results

An articulated spar as described in this study might serve as a functional alternative to buoys and fixed aids to navigation which are presently used in rivers and other high current areas. When struck, fixed structures are frequently destroyed, whereas an articulated spar, being free to rotate about its attachment point, would either move out of the way or be forced underwater until the object passed over.

To investigate such a structure, an analytical model capable of resolving the forces, moments and list angle of an articulated spar being acted upon by the forces of wind, current and waves was developed. An analysis of the major physical and environmental parameters influencing these forces and moments was made subsequently. In the relatively confined areas of a river or shipping channel, only current forces were found to contribute significantly to the motion of the spar. Further analysis revealed that in addition to current, only one other parameter, the spar weight-per-unit-length/buoyant-force-per-unit-length ratio, affected significantly a spar's list angle. An investigation of several shape related parameters, including the spar length-to-diameter ratio and the effect of varying cross-sectional areas, demonstrated that these variables affect moderately the determination of a spar's list angle.

To validate this analytical model a series of tests were performed in a circulating water channel. An elliptically cross-sectioned spar with a major-to-minor axis ratio of 2:1, moored near its leading edge, was found to be unstable in a current flow. Since the analytical model did not address directional stability, this result was not predicted. Rather than align itself with its major axis parallel to the current, the spar

would rotate so that this axis was perpendicular to the flow. Careful study revealed that this behavior was the result of an asymmetric lift force being generated either by slight perturbations in the flow or slight asymmetries in the spar shape. Subsequent attempts at improving the directional stability of this elliptical spar met with only very limited success. As a result, the scope of the testing program was expanded to include identifying a spar cross-section which was directionally stable. Numerous tests of both circular and tear-drop cross-sectioned spars revealed that of those tested only a circular cross-sectioned spar with a splitter plate had the desired directional stability characteristics over a broad range of flow conditions. A study of different splitter plates found that the minimum size necessary to ensure stability was 1.25 spar diameters in width and approximately 45% of the water depth in length. Comparison of the performance of this design shape with that predicted by the analytical model showed generally good agreement.

Based upon the results obtained in the circulating water channel tests, a field prototype spar was fabricated from nominal 6 inch (16.83 cm.) diameter schedule 40 aluminum pipe. Like the circulating water channel prototype, this spar was equipped with a splitter plate as well as two orthogonally-mounted inclinometers to measure list angles. Testing of this prototype spar took place over a four-day period during which current velocity, water depth, list angle and axial load data were recorded. After one day of testing the initial buoy configuration was altered. Shallower than expected water depths at the test site resulted in spar list angles which were frequently larger than the 45^{0} limit of range of the inclinometers. Since it was not possible to move the spar, the original configuration was modified. By removing the load cell, from

which no meaningful data had been obtained, the water depth at the spar was effectively increased by 27 inches (0.61 m.).

In the first configuration, it was observed that the spar would orient itself so that the splitter plate was upstream of the spar at low current velocities (< 0.25 ft./sec.) [7.62 cm./sec.]. To prevent this undesirable orientation from reoccurring, the mooring attachment point was shifted from the forwardmost to the aftermost location (i.e., to the hole nearest the splitter plate). Before comparing the results obtained from the spar in this second configuration with those predicted by the analytical model an analysis of the errors inherent in these field measurements was made. This analysis revealed that the error associated with the inclinometers was on the order of $\pm$ 1.3°. Current velocity and water depth measurements taken during this field test were used as input data to the analytical model. An estimated error of $\pm$ 10% in the measured current velocity was found to alter a spar's predicted list angle by only 0.1° to 0.2°. Depth measurements were estimated to have an accuracy of $\pm$ 3 inches ($\pm$ 7.62 cm.). Over the range of water depths experienced in this field test, uncertainties of this magnitude were found to significantly affect the list angle predicted by the analytical model. Despite these inherent errors, comparison of the analytical model predictions with the field test measurements showed excellent agreement, having a correlation coefficient of 0.986.

V-2 Conclusions

The general conclusion of this study is that the development of an analytical model of the forces, moments and resulting list angle on an articulated spar of circular cross-section was successful. Validation of

this model for the test spar over a broad range of environmental conditions showed generally good agreement between predicted and measured list angles. In the field test where there were several sources of error, the results obtained showed excellent agreement. Therefore, this analytical model would serve as one component of a design tool to predict the performance of a variety of articulated spars of circular cross-section under a range of current velocities. The use of this analytical model for predicting the list angle of elliptically cross-sectioned spars is not recommended without additional consideration of directional stability.

V-3 Suggestions for Future Study

During the course of this work, it became evident that research in several areas could yield additional information which would improve the design of the articulated spar.

V-3.1 A Better Shape

The use of the circulating water channel in this experiment was invaluable in facilitating the testing of numerous spar/vane shapes under a variety of conditions. Of the sections examined, the circular shape used as the basis for this study, was unquestionably the most stable. However, for a portion of this project which was not scheduled, the testing with these facilities was constrained by time and consequently was by no means exhaustive. Therefore, one potential area of future research would be the examination of additional low-drag but directionally stable shapes. Despite the problems with spar length, it is felt that because the computer analysis of this spar incorporates the use of elemental areas, Reynolds scaling of any shape could, with some slight modifications to the drag coefficient subroutines, be accomplished for any spar

shape. Unless such a shape is commercially available, the field testing of such a design could require a special extrusion and thus prove to be costly.

One possible suggestion for such a shape would be a hybrid system involving a wing-shaped device which is clamped over a circular spar. By being free to rotate about the spar axis, these airfoil shapes should reduce the overall drag on the system and be free to align themselves with the prevailing currents. Presently, similar-in-design but much more massive clamshell structures are being successfully used on oil drill risers to reduce the drag due to current forces (Chadakoff, 1978).

V-3.2 Field Test Modifications

It was clear from the field test that for the conditions and equipment available some very useful information was gathered. However, several important improvements could be made in future field tests.

Since the current velocity profile and water depth are critical input parameters to the analytical model, a more accurate determination of these values would lead to more precise predictions of the list angle. Unfortunately most areas with strong currents generally tend to have large amounts of bulky material such as seaweed suspended in the water column. Consequently, a permanently mounted current meter is likely to soon become fouled and thus its use is not suggested. However, a permanent anchor with a wire attached might be deployed in such a way that a current meter could be easily clamped to it and then lowered in a near vertical mode through the water column. If a ship with lifting capabilities were available, near-vertical orientation of a current meter could be obtained by attaching a large weight to it's base.

As an alternative to the Savonius rotor, current measurements might be obtained through other means. In this regard, one device which has been recently explored and shows promise for measuring flows in estuaries is an acoustic current meter. Because such a device has no exposed moving parts, the problem of short-term fouling is eliminated.

If additional tests were to be performed with the present spar, it is suggested that they be made in deeper water. Since the portion of the spar which is above the water surface serves only as a daymark, or platform from which to mount one, the present spar might be modified so that a small daymark shape could be attached to the top using small diameter aluminum tubing such as that used for airplane struts. In this way nearly all of the spar's length would be submerged and provide a large buoyant moment. As a result much of the large degree of sensitivity that this spar showed to small depth changes would be eliminated.

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DESIGN OF AN ARTICULATED SPAR BUOY.(U)
FEB 80 J W CUTLER DOT-CG-81-78-1882
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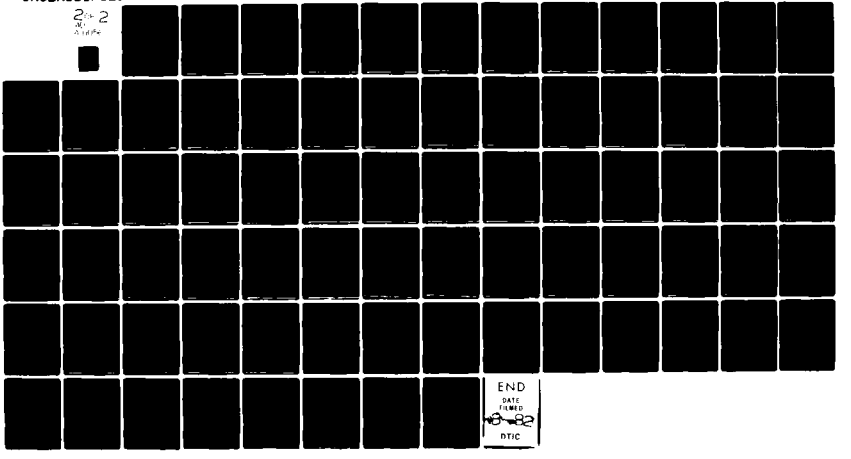

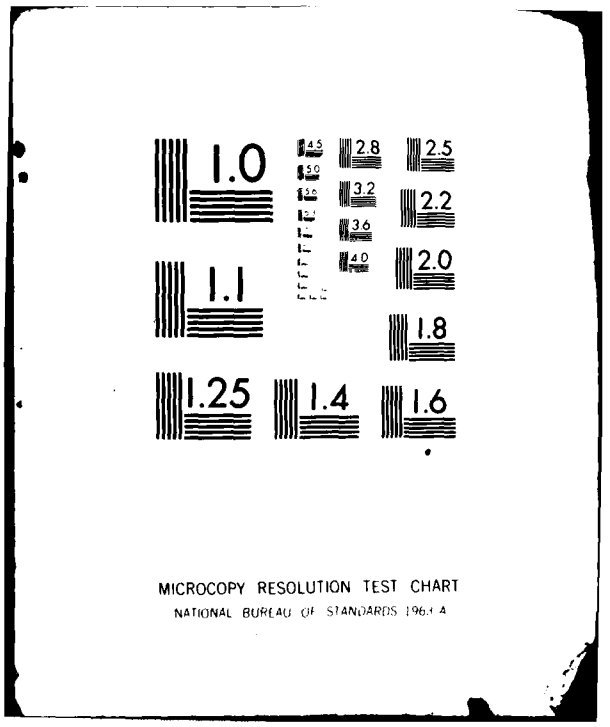
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
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4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

APPENDIX A

Listing of the Computer Model, ASB1

```
//          JOB (PJP100,320,5,7,,,,,),'JACK CUTLER'                          ASB10001
// EXEC MONITOR,REGION=320K                                                  ASB10002
//SYSIN DD *                                                                 ASB10003
/FTC                                                                        ASB10004
      CHARACTER XX*7,YY*7,ZZ*7,SM*10,VM*10,PM*10                            ASB10005
C                                                                           ASB10006
C     DIMENSION NECESSARY ARRAYS                                            ASB10007
C                                                                           ASB10008
      DIMENSION WA(100)                                                     ASB10009
      DIMENSION WSP(100),ELEV(100),Z(100),SPEED(100)                        ASB10010
      DIMENSION VEL(501),DIR(501),DEP(501),DEPC(500),CAA(501),              ASB10011
     1DEPWP(500)                                                            ASB10012
      DIMENSION WVELX(100),WVELY(100),WVELNX(100),WVELNY(100)               ASB10013
      DIMENSION CVX(500),CVY(500),CVNX(500),CVNY(500)                       ASB10014
      DIMENSION HWAVX(500),HWAVY(500),VWAVX(500),VWAVY(500)                 ASB10015
      DIMENSION XREL(500),YREL(500),AX(500),AY(500),BX(500),BY(500)         ASB10016
      DIMENSION WAVNX(500),WAVNY(500),WAVTX(500),WAVTY(500)                 ASB10017
      DIMENSION WAANX(500),WAANY(500)                                       ASB10018
      DIMENSION WPVNX(500),WPVNY(500)                                       ASB10019
      DIMENSION REWX(100),REWY(100),REWPX(500),REWPY(500)                   ASB10020
      DIMENSION CWDX(100),CWDY(100),CWPDX(500),CWPDY(500)                   ASB10021
      DIMENSION WFX(100),WFY(100)                                           ASB10022
      DIMENSION WPDFX(500),WPIFX(500),WPFX(500),WPDFY(500),                 ASB10023
     1WPIFY(500),WPFY(500)                                                  ASB10024
      DIMENSION AOL(100),TSBF(100),SBWGT(100)                               ASB10025
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY                ASB10026
      COMMON NWDP,NCDP,NWADP,NWPDP                                          ASB10027
      DATA XX/' WIND  '/,YY/'CURRENT'/,ZZ/' WAVE  '/                        ASB10028
      REAL LENGTI,M,NEWL                                                    ASB10029
C                                                                           ASB10030
C INITIALIZE CASE NUMBER                                                    ASB10031
      NCASE=1                                                               ASB10032
C                                                                           ASB10033
C DEFINE CONSTANTS                                                          ASB10034
C                                                                           ASB10035
      PI=3.141592654                                                        ASB10036
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```
      G=32.174                                                          ASB10037
      INDP1=100                                                         ASB10038
      INDP2=501                                                         ASB10039
      NEWPD=0                                                           ASB10040
C                                                                       ASB10041
C DEFINE FLUID DENSITIES                                                ASB10042
      RAIR=0.00234                                                      ASB10043
      RFW=1.93632                                                       ASB10044
      RSW=1.98918                                                       ASB10045
C                                                                       ASB10046
C DEFINE FLUID VISCOSITIES                                              ASB10047
C VISCOSITY OF WATER AT 68.4 F AND ATMOSPHERIC PRESSURE                 ASB10048
      UFW=2.083E-05                                                     ASB10049
      USW=2.067E-05                                                     ASB10050
      UAIR=3.80E-07                                                     ASB10051
C                                                                       ASB10052
C READ IN THE MAXIMUM NUMBER OF CASES TO BE COMPUTED                    ASB10053
      READ(5,20) NMAX                                                   ASB10054
      WRITE(6,43) NCASE                                                 ASB10055
C                                                                       ASB10056
C DETERMINE THE WATER DENSITY (1 = SALT; ELSE FRESH)                    ASB10057
    1 READ(5,10) IWAT                                                   ASB10058
      IF(IWAT.NE.1) GOTO 2                                              ASB10059
      RWAT=RSW                                                          ASB10060
      UWAT=USW                                                          ASB10061
      GOTO 4                                                            ASB10062
    2 RWAT=RFW                                                          ASB10063
      UWAT=UFW                                                          ASB10064
C                                                                       ASB10065
C READ IN STILL WATER DEPTH                                             ASB10066
    4 READ(5,30) DEPTH                                                  ASB10067
      WRITE(6,5) DEPTH,RWAT,UWAT                                        ASB10068
    5 FORMAT('1',/,/,/,52X,'ENVIRONMENTAL PROPERTIES',/,/,/,            ASB10069
     1/,56X,'GENERAL INFORMATION',/,/,/,40X,                            ASB10070
     2'WATER DEPTH',27X,F7.3,'  FEET',/,/,40X,                          ASB10071
     3'MASS DENSITY OF WATER',19X,F6.4,' SLUGS/FT * 3',/,/,40X,         ASB10072
```

```
     4'VISCOSITY OF WATER',17X,E11.5,' SLUGS/FT - SEC.')                ASB10073
C ***************************************************************     ASB10074
C *                                                             *     ASB10075
C *                                                             *     ASB10076
C *          INPUT SPAR BUOY STRUCTURAL INFORMATION             *     ASB10077
C *                                                             *     ASB10078
C ***************************************************************     ASB10079
C                                                                       ASB10080
C READ IN SPAR BUOY DIMENSIONS                                          ASB10081
      READ(5,50) SPL,SPW,SPD                                            ASB10082
C                                                                       ASB10083
C FORCE SPAR BUOY DEPTH TO BE THE SMALLEST DIMENSION                    ASB10084
      IF(SPD.LE.SPW) GOTO 6                                             ASB10085
      DUM=SPW                                                           ASB10086
      SPW=SPD                                                           ASB10087
      SPD=DUM                                                           ASB10088
C                                                                       ASB10089
C COMPUTE A OVER B RATIO                                                ASB10090
    6 AOB=SPW/SPD                                                       ASB10091
C                                                                       ASB10092
C READ IN BUOY'S MATERIAL PROPERTIES                                    ASB10093
      READ(5,60) SM,SMD,SWT                                             ASB10094
C                                                                       ASB10095
C ORIENTING VANE PRESENT ?                                              ASB10096
      READ(5,10) IVANE                                                  ASB10097
      IF(IVANE.EQ.1) GOTO 8                                             ASB10098
C                                                                       ASB10099
C IF NO ORIENTING VANE PRESENT, INITIALIZE VANE DIMENSIONS TO ZERO      ASB10100
      VW=0.0                                                            ASB10101
      VL=0.0                                                            ASB10102
      VT=0.0                                                            ASB10103
      VHGT=0.0                                                          ASB10104
      VMD=0.0                                                           ASB10105
      GOTO 16                                                           ASB10106
C                                                                       ASB10107
C READ IN ORIENTING VANE DIMENSIONS                                     ASB10108
    8 READ(5,50) VL,VW,VT
```

```
C                                                                       ASB10109
C READ IN ORIENTING VANE'S MATERIAL PROPERTIES                          ASB10110
      READ(5,70) VM,VMD                                                 ASB10111
C                                                                       ASB10112
C READ IN HEIGHT ABOVE THE BOTTOM OF THE LOWER EDGE OF THE              ASB10113
C ORIENTING VANE AT ZERO ANGLE OF LIST                                  ASB10114
      READ(5,30) VHGT                                                   ASB10115
C                                                                       ASB10116
C BUOY ARTICULATED OR FIXED ?                                           ASB10117
C (1 = ARTICULATED; ELSE FIXED)                                         ASB10118
   16 READ(5,10) IART                                                   ASB10119
      IF(IART.NE.1) GOTO 17                                             ASB10120
C                                                                       ASB10121
C READ IN THE COORDINATES OF THE ANCHOR ATTACHMENT POINT                ASB10122
C ON THE BOTTOM FACE OF THE BUOY                                        ASB10123
      READ(5,40) ANCHX,ANCHY                                            ASB10124
      GOTO 18                                                           ASB10125
   17 ANCHX=0.0                                                         ASB10126
      ANCHY=0.0                                                         ASB10127
C                                                                       ASB10128
C CALCULATE THE TOTAL WEIGHT OF THE SPAR BUOY AND IF ARTICULATED        ASB10129
C CHECK TO SEE IF IT HAS SUFFICIENT BUOYANCY TO FLOAT                   ASB10130
   18 CALL WEIGHT(SPL,SPW,SPD,SWT,SMD,VL,VW,VT,VMD,                    ASB10131
     1IART,CIRCUM,SWGT,VWGT,TSWGT,CAREA,VMWWD)                          ASB10132
C                                                                       ASB10133
C ECHO CHECK INPUT OF PHYSICAL DIMENSIONS OF SPAR BUOY                  ASB10134
      IF(SWT.EQ.0.0) GOTO 22                                            ASB10135
      WRITE(6,15) SPL,SPW,SPD,CIRCUM,CAREA,AOB,SM,SM,SMD,SWT,SWGT       ASB10136
   15 FORMAT('1',48X,                                                   ASB10137
     1'PHYSICAL PROPERTIES OF THE SPAR BUOY',/,/,/,/,/,55X,             ASB10138
     2'PROPERTIES OF THE SPAR',/,/,/,/,40X,                             ASB10139
     3'SPAR LENGTH',27X,F7.3,'  FEET',/,/,/,40X,                        ASB10140
     4'SPAR WIDTH',28X,F7.3,'  FEET',/,/,/,40X,                         ASB10141
     5'SPAR DEPTH',28X,F7.3,'  FEET',/,/,/,40X,                         ASB10142
     6'SPAR CIRCUMFERENCE',21X,F6.3,'  FEET',/,/,/,40X,                 ASB10143
     7'SPAR CROSS-SECTIONAL AREA',14X,F6.3,'  FEET ** 2',/,/,/,40X,     ASB10144
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     8'SPAR WIDTH TO DEPTH RATIO',14X,F6.3,/,/,40X,                    ASB10145
     9'SPAR MATERIAL',26X,A10,/,/,40X,                                 ASB10146
     X'MASS DENSITY OF ',A10,12X,F7.3,'  SLUGS/FT * 3',/,/,40X,        ASB10147
     1'SPAR WALL THICKNESS',21X,F6.4,' FEET',/,/,40X,                  ASB10148
     2'WEIGHT OF SPAR IN AIR',16X,F8.3,'  POUNDS')                     ASB10149
      GOTO 24                                                          ASB10150
  22 WRITE(6,25) SPL,SPW,SPD,CIRCUM,CAREA,AOB,SM,SM,SMD,SWGT           ASB10151
  25 FORMAT('1',48X,                                                   ASB10152
     1'PHYSICAL PROPERTIES OF THE SPAR BUOY',/,/,/,/,/,55X,            ASB10153
     2'PROPERTIES OF THE SPAR',/,/,/,40X,                              ASB10154
     3'SPAR LENGTH',27X,F7.3,'  FEET',/,/,40X,                         ASB10155
     4'SPAR WIDTH',28X,F7.3,'  FEET',/,/,40X,                          ASB10156
     5'SPAR DEPTH',28X,F7.3,'  FEET',/,/,40X,                          ASB10157
     6'SPAR CIRCUMFERENCE',21X,F6.3,'  FEET',/,/,40X,                  ASB10158
     7'SPAR CROSS-SECTIONAL AREA',14X,F6.3,'  FEET ** 2',/,/,40X,      ASB10159
     8'SPAR WIDTH TO DEPTH RATIO',14X,F6.3,/,/,40X,                    ASB10160
     9'SPAR MATERIAL',26X,A10,/,/,40X,                                 ASB10161
     X'MASS DENSITY OF ',A10,12X,F7.3,'  SLUGS/FT * 3',/,/,40X,        ASB10162
     1'WEIGHT OF SPAR IN AIR',16X,F8.3,'  POUNDS',/,/,/,/,47X,         ASB10163
     2'SPAR IS A SOLID (NON HOLLOW) STRUCTURE')                        ASB10164
  24 IF(IART.EQ.1) GOTO 26                                             ASB10165
      WRITE(6,35)                                                      ASB10166
  35 FORMAT(' ',/,/,/,/,47X,                                           ASB10167
     1'SPAR BUOY IS FIXED AT THE OCEAN BOTTOM')                        ASB10168
      GOTO 28                                                          ASB10169
  26 WRITE(6,45) ANCHX,ANCHY                                           ASB10170
  45 FORMAT(' ',/,/,/,/,44X,                                           ASB10171
     1'SPAR BUOY IS ARTICULATED AT THE OCEAN BOTTOM',/,/,40X,          ASB10172
     2'ANCHOR ATTACHMENT HAS COORDINATES (',F7.4,1X,F7.4,')',/,43X,     ASB10173
     3'(IN FEET) RELATIVE TO THE CENTER OF THE BUOY')                  ASB10174
  28 IF(IVANE.EQ.1) GOTO 32                                            ASB10175
      WRITE(6,55)                                                      ASB10176
  55 FORMAT('1',42X,                                                   ASB10177
     1'PHYSICAL PROPERTIES OF THE SPAR BUOY (CONTINUED)',/,/,/,/,49X,  ASB10178
     2'NO ORIENTING VANE IN THIS ANALYSIS')                            ASB10179
      GOTO 42                                                          ASB10180
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   32 WRITE(6,65) VL,VW,VT,VM,VM,VMD,VHGT,VWGT                          ASB10181
   65 FORMAT('1',42X,                                                   ASB10182
     1'PHYSICAL PROPERTIES OF THE SPAR BUOY (CONTINUED)',/,/,/,49X,     ASB10183
     2'PROPERTIES OF THE ORIENTING VANE',/,/,40X,                       ASB10184
     3'VANE LENGTH',28X,F6.3,'  FEET',/,/,40X,                          ASB10185
     4'VANE WIDTH',29X,F6.3,'  FEET',/,/,40X,                           ASB10186
     5'VANE THICKNESS = ',23X,F6.4,' FEET',/,/,40X,                     ASB10187
     6'VANE MATERIAL = ',24X,A10,/,/,40X,                               ASB10188
     7'MATERIAL DENSITY OF ',A10,' =',6X,F7.3,'  SLUGS/FT**3',/,/,      ASB10189
     840X,                                                              ASB10190
     9'VANE HEIGHT ABOVE THE BOTTOM',11X,F6.3,'  FEET',/,/,40X,         ASB10191
     X'VANE WEIGHT = ',24X,F7.3,'  POUNDS')                             ASB10192
C ******************************************************************   ASB10193
C *                                                                *   ASB10194
C *          INPUT FORCES ACTING ON THE SPAR BUOY                  *   ASB10195
C *                                                                *   ASB10196
C ******************************************************************   ASB10197
C                                                                       ASB10198
C                                                                       ASB10199
C     INPUT WIND FORCE INFORMATION                                      ASB10200
C                                                                       ASB10201
C                                                                       ASB10202
C IF NO NEW PHYSICAL DATA, WRITE OUT NEW CASE NUMBER                    ASB10203
C                                                                       ASB10204
   42 IF(NEWPD.NE.1) WRITE(6,43) NCASE                                  ASB10205
C READ IN THE NUMBER OF WIND DATA POINTS                                ASB10206
      READ(5,20) NWDP                                                   ASB10207
      IF(NWDP.EQ.0) GOTO 44                                             ASB10208
      IF(NWDP.LT.100) GOTO 46                                           ASB10209
      IF(NWDP.EQ.999) GOTO 1000                                         ASB10210
      WRITE(6,105) XX,NWDP,INDP1,XX                                     ASB10211
      STOP                                                              ASB10212
   46 READ(5,60) WSPD,WDIR,WELEV,FETCH                                  ASB10213
C                                                                       ASB10214
C CONVERT MILES PER HOUR TO FEET PER SECOND                             ASB10215
      WSPD=WSPD*5280./3600.                                             ASB10216
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C                                                                       ASB10217
C CONVERT WIND SPEED REFERENCE ELEVATION FROM FEET TO METERS            ASB10218
      WELEV=WELEV*0.3048                                                ASB10219
C                                                                       ASB10220
C COMPUTE WIND SPEED AT THE 10 METER REFERENCE ELEVATION                ASB10221
      ZO=3.0E-03                                                        ASB10222
      WSPD=WSPD/(ALOG(WELEV/ZO)/ALOG(10./ZO))                           ASB10223
C                                                                       ASB10224
C ECHO CHECK WIND FORCE INFORMATION                                     ASB10225
      DO 48 I=1,10                                                      ASB10226
   48 ELEV(I)=FLOAT(I)                                                  ASB10227
      CALL WNDSPD(WSPD,ELEV,10,SPEED)                                   ASB10228
      WRITE(6,115)                                                      ASB10229
      WRITE(6,43) NCASE                                                 ASB10230
  115 FORMAT('1',/,/,/,/,55X,'WIND FORCE INFORMATION',/,/,/,/,55X,       ASB10231
     1'NEAR SURFACE WIND PROFILE',/,/,28X,'ELEVATION',25X,              ASB10232
     2'WIND SPEED',25X,'WIND DIRECTION',/,28X,                          ASB10233
     3'(METERS)',27X,'(FT/SEC)',25X,                                    ASB10234
     4'(DEG. MAGNETIC)')                                                ASB10235
      DO 52 I=1,10                                                      ASB10236
   52 WRITE(6,125) ELEV(I),SPEED(I),WDIR                                ASB10237
  125 FORMAT('0',30X,F3.0,30X,F5.2,32X,F5.1)                            ASB10238
      WRITE(6,135) FETCH                                                ASB10239
  135 FORMAT(' ',/,/,/,/,51X,'FETCH LENGTH = ',F10.0,' FEET')           ASB10240
      GOTO 62                                                           ASB10241
   44 WRITE(6,145)                                                      ASB10242
  145 FORMAT('1',/,/,/,/,55X,'WIND FORCE INFORMATION',/,/,/,/,48X,       ASB10243
     1'NO WIND FORCE PRESENT IN THIS ANALYSIS')                         ASB10244
C                                                                       ASB10245
C                                                                       ASB10246
C     INPUT CURRENT FORCE INFORMATION                                   ASB10247
C                                                                       ASB10248
C                                                                       ASB10249
C READ IN THE NUMBER OF CURRENT DATA POINTS                             ASB10250
   62 READ(5,20) NCDP                                                   ASB10251
      IF(NCDP.EQ.0) GOTO 64                                             ASB10252
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      IF(NCDP.LE.500) GOTO 66                                          ASB10253
      WRITE(6,105) YY,NCDP,INDP2,YY                                    ASB10254
      STOP                                                             ASB10255
   66 NCDPT=NCDP+1                                                     ASB10256
C                                                                      ASB10257
C CURRENT SPEED AND DIRECTION UNIFORM ???                              ASB10258
C      (1 = YES; 0 = NO)                                               ASB10259
      READ(5,10) ICUR                                                  ASB10260
      IF(ICUR.NE.1) GOTO 68                                            ASB10261
C                                                                      ASB10262
C READ IN UNIFORM CURRENT SPEED AND DIRECTION                          ASB10263
      READ(5,40) UCVEL,UCDIR                                           ASB10264
      DO 72 I=1,NCDPT                                                  ASB10265
      VEL(I)=UCVEL                                                     ASB10266
      DIR(I)=UCDIR                                                     ASB10267
      J=I-1                                                            ASB10268
   72 DEP(I)=DEPTH/FLOAT(NCDP)*J                                       ASB10269
      GOTO 74                                                          ASB10270
C                                                                      ASB10271
C READ IN CURRENT VELOCITY AND DIRECTION AT EACH DEPTH OF INTEREST     ASB10272
   68 DO 76 I=1,NCDPT                                                  ASB10273
   76 READ(5,50) VEL(I),DIR(I),DEP(I)                                  ASB10274
      DELTD=DEP(2)-DEP(1)                                              ASB10275
      DO 78 I=3,NCDPT                                                  ASB10276
      DELTX=DEP(I)-DEP(I-1)                                            ASB10277
      IF(DELTX.NE.DELTD) GOTO 82                                       ASB10278
   78 CONTINUE                                                         ASB10279
      GOTO 74                                                          ASB10280
   82 WRITE(6,205)                                                     ASB10281
  205 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,56X,                        ASB10282
     1'*** CHECK DATA ***',/,/,/,/,/,35X,                              ASB10283
     2'CURRENT VELOCITY VALUES NOT AT EQUALLY SPACED INTERVALS',       ASB10284
     3/,/,/,/,/,56X,                                                   ASB10285
     4'CORRECT AND RESUBMIT')                                          ASB10286
      STOP                                                             ASB10287
C                                                                      ASB10288
```

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C COMPUTE AVERAGE CURRENT VELOCITY                                       ASB10289
   74 TOTALX=0.0                                                         ASB10290
      TOTALY=0.0                                                         ASB10291
      DO 73 I=1,NCDPT                                                    ASB10292
      CVX(I)=VEL(I)*COS(DIR(I)*PI/180.)                                  ASB10293
      CVY(I)=VEL(I)*SIN(DIR(I)*PI/180.)                                  ASB10294
      TOTALX=TOTALX+CVX(I)                                               ASB10295
   73 TOTALY=TOTALY+CVY(I)                                               ASB10296
      AVGX=TOTALX/FLOAT(NCDPT)                                           ASB10297
      AVGY=TOTALY/FLOAT(NCDPT)                                           ASB10298
      AVCVEL=SQRT(AVGX**2+AVGY**2)                                       ASB10299
      AVCDIR=ATAN(AVGY/AVGX)*180./PI                                     ASB10300
      IF(AVGX.LT.0.00) AVCDIR=AVCDIR+180.                                ASB10301
      IF(AVCDIR.LT.0.00) AVCDIR=AVCDIR+360.                              ASB10302
C                                                                        ASB10303
C ECHO CHECK CURRENT FORCE INFORMATION                                   ASB10304
      WRITE(6,215)                                                       ASB10305
  215 FORMAT('1',53X,'CURRENT FORCE INFORMATION',/,/,/,58X,              ASB10306
     1'CURRENT PROFILE',/,/,24X,'DEPTH',25X,'CURRENT SPEED',25X,         ASB10307
     2'CURRENT DIRECTION',/,23X,'(FEET)',28X,'(FT/SEC)',28X,             ASB10308
     3'(DEG. MAGNETIC)')                                                 ASB10309
      DO 84 I=1,NCDPT                                                    ASB10310
   84 WRITE(6,225) DEP(I),VEL(I),DIR(I)                                  ASB10311
  225 FORMAT('0',23X,F5.2,30X,F5.2,33X,F5.1)                             ASB10312
      GOTO 92                                                            ASB10313
   64 WRITE(6,235)                                                       ASB10314
  235 FORMAT('1',/,/,/,/,53X,'CURRENT FORCE INFORMATION',/,/,/,/,45X,    ASB10315
     1'NO CURRENT FORCE PRESENT IN THIS ANALYSIS')                       ASB10316
C                                                                        ASB10317
C                                                                        ASB10318
C     INPUT WAVE FORCE INFORMATION                                       ASB10319
C                                                                        ASB10320
C                                                                        ASB10321
C READ IN THE NUMBER OF WAVE DATA POINTS                                 ASB10322
   92 READ(5,20) NWADP                                                   ASB10323
      IF(NWADP.EQ.0) GOTO 94                                             ASB10324
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      IF(NWADP.LE.500) GOTO 96                                          ASB10325
      WRITE(6,105) ZZ,NWADP,INDP2,ZZ                                    ASB10326
      STOP                                                              ASB10327
   96 IF((NCDP.EQ.0).OR.(NCDP.EQ.NWADP)) GOTO 98                        ASB10328
      IF(NWADP.GT.NCDP) GOTO 102                                        ASB10329
      WRITE(6,305) NWADP,NCDP,NCDP                                      ASB10330
  305 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,                       ASB10331
     1'SPECIFIED NUMBER OF WAVE DATA POINTS WAS ',I3,/,/,/,42X,         ASB10332
     2'SPECIFIED NUMBER OF CURRENT DATA POINTS IS ',I3,/,/,/,44X,       ASB10333
     3'NUMBER OF WAVE DATA POINTS INCREASED TO ',I3,/,/,/,30X,          ASB10334
     4'WHEN BOTH CURRENT AND WAVE FORCES ARE PRESENT, THE               ASB10335
     5 NUMBER OF WAVE DATA POINTS',/,25X,                               ASB10336
     6'MUST EQUAL THE NUMBER OF CURRENT DATA POINTS IN ORDER THAT       ASB10337
     7THE TOTAL PARTICLE VELOCITY',/,25X,                               ASB10338
     8'AT EACH POINT OF STUDY BE CORRECTLY CALCULATED')                 ASB10339
      NWADP=NCDP                                                        ASB10340
      GOTO 98                                                           ASB10341
  102 WRITE(6,315) NWADP,NCDP,NCDP                                      ASB10342
  315 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,42X,                       ASB10343
     1'SPECIFIED NUMBER OF WAVE DATA POINTS IS ',I3,/,/,/,/,41X,        ASB10344
     2'SPECIFIED NUMBER OF CURRENT DATA POINTS IS ',I3,/,/,/,30X,       ASB10345
     3'EITHER THE NUMBER OF WAVE DATA POINTS MUST BE REDUCED TO         ASB10346
     4 EQUAL ',I3,', THE ',/,25X,                                       ASB10347
     5'NUMBER OF CURRENT DATA POINTS OR THE SPECIFIED NUMBER OF         ASB10348
     6 CURRENT DATA POINTS MUST ',/,25X,                                ASB10349
     7'BE INCREASED TO EQUAL THE NUMBER OF WAVE DATA POINTS. IF THE     ASB10350
     8 NUMBER OF CURRENT DATA',/,25X,                                   ASB10351
     9' POINTS IS INCREASED THEN ADDITIONAL CURRENT DATA VALUES         ASB10352
     X MUST BE ADDED TO THE INPUT',/,25X,                               ASB10353
     1' DATA FILE.')                                                    ASB10354
      STOP                                                              ASB10355
   98 NWADPT=NWADP+1                                                    ASB10356
C                                                                       ASB10357
C WAVE INFORMATION SUPPLIED BY USER OR CALCULATED FROM THE WIND         ASB10358
C INFORMATION USING THE S.M.B. METHOD ?                                 ASB10359
      READ(5,10) IWAVE                                                  ASB10360
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      IF(IWAVE.EQ.1) GOTO 104                                          ASB10361
      CALL WAVSMB(WSPD,FETCH,TSIG,TAVG,HGTSIG,HGTAVG)                  ASB10362
      GOTO 106                                                         ASB10363
  104 READ(5,80) TSIG,TAVG,HGTSIG,HGTAVG                               ASB10364
C                                                                      ASB10365
C READ IN THE NUMBER OF TIME INCREMENTS THE WAVE PERIOD IS              ASB10366
C TO BE DIVIDED INTO                                                   ASB10367
  106 READ(5,20) ITIME                                                 ASB10368
      IF(ITIME.LE.99) GOTO 108                                         ASB10369
      WRITE(6,320) ITIME                                               ASB10370
  320 FORMAT('1',/,/,/,/,/,/,54X,                                      ASB10371
     1'ITIME DECLARED AS = ',I3,/,/,/,/,45X,                           ASB10372
     2'THIS NUMBER MUST BE REDUCED TO 99 OR LESS',/,48X,               ASB10373
     3'ELSE THE WAVE HEIGHT, ANGLE OF LIST',/,48X,                     ASB10374
     4'TOTAL SPAR BUOY FORCE AND TOTAL SPAR',/,46X,                    ASB10375
     5'WEIGHT ARRAYS MUST BE REDIMENSIONED')                           ASB10376
      STOP                                                             ASB10377
  108 NWHPTS=ITIME+1                                                   ASB10378
C                                                                      ASB10379
C LINEAR (AIRY) OR STOKES SECOND ORDER WAVE THEORY ?                   ASB10380
      READ(5,10) ITHERY                                                ASB10381
      IF((ITHERY.EQ.1).OR.(ITHERY.EQ.2)) GOTO 112                      ASB10382
      WRITE(6,325)                                                     ASB10383
  325 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,39X,                        ASB10384
     1'CHOICE OF APPROPRIATE WAVE THEORY SPECIFIED INCORRECTLY',       ASB10385
     2/,/,/,/,/,41X,                                                   ASB10386
     3'ACCEPTABLE WAVE THEORY INPUT VALUES ARE :  1 - LINEAR (AIRY)',  ASB10387
     4/,78X,                                                           ASB10388
     5'WAVE THEORY',/,/,/,/,73X,                                       ASB10389
     6'2 - STOKES SECOND',/,78X,                                       ASB10390
     7'ORDER WAVE THEORY')                                             ASB10391
      STOP                                                             ASB10392
C                                                                      ASB10393
C ECHO CHECK AND CALCULATE ADDITIONAL WAVE INFORMATION                 ASB10394
  112 CALL WAVE(TSIG,TAVG,HGTSIG,HGTAVG,NWHPTS,ITHERY,WVNO,SIG,        ASB10395
     1WAMP,C,DELTAT,WA)                                                ASB10396
```

```
      GOTO 122                                                          ASB10397
   94 WRITE(6,335)                                                      ASB10398
  335 FORMAT('1',/,/,/,/,55X,'WAVE FORCE INFORMATION',/,/,/,/,48X,      ASB10399
     1'NO WAVE FORCE PRESENT IN THIS ANALYSIS')                         ASB10400
C                                                                       ASB10401
C OUTPUT OF INTERMEDIATE VALUES DESIRED ?                               ASB10402
C (1 = YES; 0 = NO)                                                     ASB10403
  122 READ(5,10) ION                                                    ASB10404
C                                                                       ASB10405
C IF WAVES ARE PRESENT DETERMINE THE PRESENT WAVE AMPLITUDE             ASB10406
      IF(NWADP.NE.0) GOTO 124                                           ASB10407
      NWHPTS=1                                                          ASB10408
      WA(1)=0.0                                                         ASB10409
  124 DO 126 N=1,NWHPTS                                                 ASB10410
      PWAMP=WA(N)                                                       ASB10411
C                                                                       ASB10412
C INITIALIZE ANGLES OF LIST AND OTHER COUNTERS                          ASB10413
      AOLX=00.00                                                        ASB10414
      AOLY=00.00                                                        ASB10415
      ICOUNT=0                                                          ASB10416
      KCOUNT=0                                                          ASB10417
      LCOUNT=0                                                          ASB10418
      XFAC=10.0                                                         ASB10419
      YFAC=10.0                                                         ASB10420
  100 CONTINUE                                                          ASB10421
      ICOUNT=ICOUNT+1                                                   ASB10422
C                                                                       ASB10423
C CHECK TO MAKE SURE THAT THE TOP OF THE SPAR BUOY                      ASB10424
C IS ABOVE WATER                                                        ASB10425
      PSPL=SPL*COS(AOLX*PI/180.)*COS(AOLY*PI/180.)                      ASB10426
      TD=DEPTH+WA(N)                                                    ASB10427
      IF(PSPL.LT.TD) GOTO 200                                           ASB10428
      PSPLAW=PSPL-TD                                                    ASB10429
      CALL AREAS(SPL,SPD,SPW,EWAX,EWAY,                                 ASB10430
     1ECAX,ECAY,EWAAX,EWAAY)                                            ASB10431
C                                                                       ASB10432
```

```
C DETERMINE BUOY ORIENTATION                                          ASB10433
C                                                                     ASB10434
      IF(NCDP.EQ.0) GOTO 202                                          ASB10435
      IF(IVANE.NE.1) GOTO 203                                         ASB10436
      CALL CBEAR(VEL,DIR,DEP,VL,VW,VHGT,DIRV,BEAR)                    ASB10437
      GOTO 204                                                        ASB10438
  203 BEAR=AVCDIR+180.                                                ASB10439
      IF(BEAR.GT.360) BEAR=BEAR-360.                                  ASB10440
  204 IWIND=1                                                         ASB10441
      GOTO 206                                                        ASB10442
  202 IF(NWDP.EQ.0) GOTO 208                                          ASB10443
C                                                                     ASB10444
C IF NO CURRENT PRESENT THEN BUOY ORIENTS ITSELF TOWARDS THE WIND     ASB10445
      BEAR=WDIR                                                       ASB10446
      WAA=000.00                                                      ASB10447
      IWIND=2                                                         ASB10448
      GOTO 206                                                        ASB10449
C                                                                     ASB10450
C IF NO CURRENT OR WIND PRESENT THEN BEARING SET EQUAL TO ZERO        ASB10451
  208 BEAR=000.00                                                     ASB10452
      WAA=000.00                                                      ASB10453
      IWIND=3                                                         ASB10454
C                                                                     ASB10455
C DETERMINE THE RELATIVE WIND, CURRENT AND WAVE PARTICLE VELOCITIES   ASB10456
C                                                                     ASB10457
  206 IF(NWDP.NE.0) CALL RWVEL(BEAR,PSPLAW,WSPD,WDIR,                 ASB10458
     1ELEV,WAA,WSP,WVELX,WVELNX,WVELY,WVELNY)                         ASB10459
      IF(NCDP.NE.0) CALL RCVEL(BEAR,DIR,VEL,CAA,DEPC,CVX,CVY,         ASB10460
     1CVNX,CVNY)                                                      ASB10461
      IF(NWADP.NE.0) CALL RWAVA(NWADPT,ITHERY,DELTAT,WAMP,            ASB10462
     1SIG,N,WVNO,WAA,C,HWAVX,HWAVY,VWAVX,VWAVY,WAVNX,                 ASB10463
     2WAVNY,WAANX,WAANY)                                              ASB10464
C                                                                     ASB10465
C COMPUTE AVERAGE ANGLE OF ATTACK                                     ASB10466
      IF(NCDP.EQ.0) GOTO 209                                          ASB10467
      TOTALX=0.0                                                      ASB10468
```

```
      TOTALY=0.0                                                        ASB10469
      DO 212 I=1,NCDP                                                   ASB10470
      TOTALX=TOTALX+CVX(I)                                              ASB10471
  212 TOTALY=TOTALY+CVY(I)                                              ASB10472
      AVGX=TOTALX/FLOAT(NCDP)                                           ASB10473
      AVGY=TOTALY/FLOAT(NCDP)                                           ASB10474
      AVCAA=ATAN(AVGY/AVGX)*180./PI                                     ASB10475
      GOTO 214                                                          ASB10476
  209 AVCVEL=0.0                                                        ASB10477
      AVCDIR=0.0                                                        ASB10478
      AVCAA=0.0                                                         ASB10479
C                                                                       ASB10480
C DETERMINE WATER PARTICLE VELOCITIES BY COMBINING CURRENT              ASB10481
C AND WAVE PARTICLE VELOCITIES                                          ASB10482
  214 IF((NCDP.EQ.0).AND.(NWADP.EQ.0)) GOTO 222                         ASB10483
      IF((NCDP.NE.0).AND.(NWADP.EQ.0)) GOTO 224                         ASB10484
      IF((NCDP.EQ.0).AND.(NWADP.NE.0)) GOTO 226                         ASB10485
      IF(NCDP.EQ.NWADP) GOTO 216                                        ASB10486
      WRITE(6,345) NCDP,NWADP                                           ASB10487
  345 FORMAT('1',/,/,/,/,/,/,46X,                                       ASB10488
     1'NUMBER OF CURRENT DATA POINTS NOT EQUAL',/,49X,                  ASB10489
     2'TO THE NUMBER OF WAVE DATA POINTS',/,/,/,/,/,/,48X,              ASB10490
     3'NUMBER OF CURRENT DATA POINTS = ',I3,/,/,50X,                    ASB10491
     4'NUMBER OF WAVE DATA POINTS = ',I3)                               ASB10492
      STOP                                                              ASB10493
  216 NWPDP=NCDP                                                        ASB10494
      EWPAX=ECAX                                                        ASB10495
      EWPAY=ECAY                                                        ASB10496
      DO 218 I=1,NWPDP                                                  ASB10497
      WPVNX(I)=CVNX(I)+WAVNX(I)                                         ASB10498
  218 WPVNY(I)=CVNY(I)+WAVNY(I)                                         ASB10499
      GOTO 232                                                          ASB10500
  222 NWPDP=0                                                           ASB10501
      GOTO 232                                                          ASB10502
  224 NWPDP=NCDP                                                        ASB10503
      EWPAX=ECAX                                                        ASB10504
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      EWPAY=ECAY                                                        ASB10505
      DO 228 I=1,NWPDP                                                  ASB10506
      WAANX(I)=0.0                                                      ASB10507
      WAANY(I)=0.0                                                      ASB10508
      WPVNX(I)=CVNX(I)                                                  ASB10509
  228 WPVNY(I)=CVNY(I)                                                  ASB10510
      GOTO 232                                                          ASB10511
  226 NWPDP=NWADP                                                       ASB10512
      EWPAX=EWAAX                                                       ASB10513
      EWPAY=EWAAY                                                       ASB10514
      DO 229 I=1,NWPDP                                                  ASB10515
      WPVNX(I)=WAVNX(I)                                                 ASB10516
  229 WPVNY(I)=WAVNY(I)                                                 ASB10517
C                                                                       ASB10518
C CHECK FOR THE DEGENERATE CASE OF ELLIPTICAL CROSS-SECTION OF          ASB10519
C THE SPAR BUOY BEING A CIRCLE.                                         ASB10520
  232 IF(SPL.EQ.SPW) GOTO 234                                           ASB10521
      CALL DRAGC(WVELNX,WPVNX,SPD,PSPLAW,DEPWP,REWX,                    ASB10522
     1REWPX,CWDX,CWPDX)                                                 ASB10523
      CALL DRAGC(WVELNY,WPVNY,SPD,PSPLAW,DEPWP,REWY,                    ASB10524
     1REWPY,CWDY,CWPDY)                                                 ASB10525
      GOTO 236                                                          ASB10526
  234 CALL DRAGX(WVELNX,WPVNX,SPD,SPW,PSPLAW,DEPWP,                     ASB10527
     1REWX,REWPX,CWDX,CWPDX)                                            ASB10528
      CALL DRAGY(WVELNY,WPVNY,SPD,SPW,PSPLAW,REWY,                      ASB10529
     1REWPY,CWDY,CWPDY)                                                 ASB10530
  236 CALL FORCE(N,NWHPTS,SPD,SPW,CAREA,EWAX,EWAY,                      ASB10531
     1EWPAX,EWPAY,WVELNX,WVELNY,WPVNX,WPVNY,WAANX,WAANY,                ASB10532
     2CWDX,CWDY,CWPDX,CWPDY,CMX,CMY,WFX,WFY,TWFX,TWFY,                  ASB10533
     3WPDFX,WPDFY,WPIFX,WPIFY,WPFX,WPFY,TWPDFX,TWPDFY,                  ASB10534
     4TWPIFX,TWPIFY,TWPFX,TWPFY,TFX,TFY,TSBF)                           ASB10535
C                                                                       ASB10536
C SET END CAP FLAG                                                      ASB10537
      IEND=1                                                            ASB10538
C                                                                       ASB10539
C COMPUTE OVERTURNING MOMENTS                                           ASB10540
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      CALL OTMOM(WFX,WFY,WPFX,WPFY,PSPLAW,PWAMP,CAREA,SPL,                ASB10541
     1SWWD,VL,VHGT,VWWND,IVSUB,VWWD,TBWGT,TSWGT,ANCHX,ANCHY,IEND,        ASB10542
     2WOTMX,WOTMY,WPOTMX,WPOTMY,OTMOMX,OTMOMY)                           ASB10543
      IF(IART.NE.1) GOTO 460                                             ASB10544
C                                                                        ASB10545
C COMPUTE RIGHTING MOMENTS                                               ASB10546
      CALL RMOM(SPL,SPW,VW,VL,VHGT,SWGT,VWGT,PWAMP,SWWD,VWWD,IVSUB,      ASB10547
     1WWMOMX,WWMOMY,BMOMX,BMOMY,RMOMX,RMOMY)                             ASB10548
C                                                                        ASB10549
C ITERATE THE LIST ANGLE UNTIL THE OVERTURNING MOMENT IS                 ASB10550
C EQUAL TO THE RIGHTING MOMENT                                           ASB10551
      DIFFX=OTMOMX-RMOMX                                                 ASB10552
      DIFFY=OTMOMY-RMOMY                                                 ASB10553
      IF(ABS(DIFFY).GT.ABS(DIFFX)) GOTO 395                              ASB10554
      IF(DIFFX.GT.0.02) GOTO 300                                         ASB10555
      IF(DIFFX.LT.-0.02) GOTO 350                                        ASB10556
  395 IF(DIFFY.GT.0.02) GOTO 400                                         ASB10557
      IF(DIFFY.LT.-0.02) GOTO 450                                        ASB10558
      GOTO 460                                                           ASB10559
  300 KCOUNT=KCOUNT+1                                                    ASB10560
      IF(KCOUNT.EQ.1) XFAC=XFAC/10.0                                     ASB10561
      AOLX=AOLX+XFAC                                                     ASB10562
      GOTO 100                                                           ASB10563
  350 AOLX=AOLX-XFAC/10.0                                                ASB10564
      KCOUNT=0                                                           ASB10565
      GOTO 100                                                           ASB10566
  400 LCOUNT=LCOUNT+1                                                    ASB10567
      IF(LCOUNT.EQ.1) YFAC=YFAC/10.0                                     ASB10568
      AOLY=AOLY+YFAC                                                     ASB10569
      GOTO 100                                                           ASB10570
  450 AOLY=AOLY-YFAC/10.0                                                ASB10571
      LCOUNT=0                                                           ASB10572
      GOTO 100                                                           ASB10573
C *************************************************************        ASB10574
C *                                                           *        ASB10575
C *                        FINAL OUTPUT                       *        ASB10576
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C *                                                                    *   ASB10577
C ********************************************************************   ASB10578
C WRITE OUT BUOY ORIENTATION                                               ASB10579
  460 IF(IWIND.EQ.1) WRITE(6,505) BEAR                                     ASB10580
      IF(IWIND.EQ.2) WRITE(6,515) BEAR                                     ASB10581
      IF(IWIND.EQ.3) WRITE(6,525) BEAR                                     ASB10582
C                                                                          ASB10583
C WRITE OUT INTERMEDIATE VALUES IF DESIRED                                 ASB10584
      IF(ION.EQ.1) CALL INOUT1(ELEV,                                       ASB10585
     1WAA,WSP,WVELX,WVELY,WVELNX,WVELNY,DEPC,DEPWP,VEL,DIR,CAA,CVX,        ASB10586
     2CVY,CVNX,CVNY,DEP,PWAMP,HWAVX,HWAVY,VWAVX,VWAVY,WAVNX,WAVNY,         ASB10587
     3WAVTX,WAVTY,XREL,YREL,AX,AY,BX,BY,WPVNX,WPVNY,SPW,SPD,               ASB10588
     4REWX,REWY,REWPX,REWPY,CWDX,CWDY,CWPDX,CWPDY)                         ASB10589
      IF(ION.EQ.1) CALL INOUT2(EWAX,EWAY,CAREA,CMX,CMY,                    ASB10590
     1ELEV,WFX,WFY,TWFX,TWFY,EWPAX,EWPAY,DEPWP,WPDFX,WPDFY,WPIFX,          ASB10591
     2WPIFY,WPFX,WPFY,TWPDFX,TWPDFY,TWPIFX,TWPIFY,TWPFX,TWPFY,             ASB10592
     3WOTMX,WOTMY,WPOTMX,WPOTMY,OTMOMX,OTMOMY,IART,WMOMX,WMOMY,            ASB10593
     4BMOMX,BMOMY,RMOMX,RMOMY)                                             ASB10594
      IF(IART.EQ.1) GOTO 470                                               ASB10595
      IF(N.EQ.1) WRITE(6,475)                                              ASB10596
      WRITE(6,485) N,TFX,TFY,TSBF(N),OTMOMX,OTMOMY                         ASB10597
      GOTO 126                                                             ASB10598
C                                                                          ASB10599
C COMPUTE THE WATCH CIRCLE RADIUS AND THE TOTAL LIST ANGLE                 ASB10600
  470 XSPL=DEPTH*TAN(AOLX*PI/180.)                                         ASB10601
      YSPL=DEPTH*TAN(AOLY*PI/180.)                                         ASB10602
      WCR=SQRT(XSPL**2+YSPL**2)                                            ASB10603
      AOL(N)=ATAN(WCR/DEPTH)*180./PI                                       ASB10604
      IF(AOLX.LT.0.00) AOL(N)=-AOL(N)                                      ASB10605
      SBWGT(N)=TBWGT                                                       ASB10606
C                                                                          ASB10607
C WRITE OUT FINAL RESULTS                                                  ASB10608
      WRITE(6,605) AVCVEL,AVCDIR,AVCAA,PWAMP,ICOUNT,                       ASB10609
     1AOLX,OTMOMX,RMOMX,AOLY,OTMOMY,RMOMY,WCR,AOL(N)                       ASB10610
      GOTO 126                                                             ASB10611
  200 WRITE(6,615) AVCVEL,AVCDIR,AVCAA,PWAMP,ICOUNT,SPL,AOLX,              ASB10612
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     1AOLY,PSPL,DEPTH,TD                                                    ASB10613
      TSBF(N)=00.00                                                         ASB10614
      AOL(N)=00.00                                                          ASB10615
      SBWGT(N)=00.00                                                        ASB10616
  126 CONTINUE                                                              ASB10617
      WRITE(6,705) NCASE                                                    ASB10618
  705 FORMAT('1',58X,'CASE NUMBER ',I3,/,/,57X,                             ASB10619
     1'SUMMARY OF RESULTS',/,/,33X,                                         ASB10620
     2'STEP',22X,'TOTAL FORCE',22X,'RESULTANT',/,33X,                       ASB10621
     3'NUMBER',24X,'(LBS.)',23X,'LIST ANGLE')                               ASB10622
      DO 710 N=1,NWHPTS                                                     ASB10623
  710 WRITE(6,715) N,TSBF(N),AOL(N)                                         ASB10624
  715 FORMAT('0',33X,I3,20X,F11.3,27X,F6.3)                                 ASB10625
      IF((NWADP.EQ.0).AND.(SBWGT(1).EQ.0.00)) GOTO 716                      ASB10626
      CALL ANCHOR(NWHPTS,TSWGT,SBWGT)                                       ASB10627
C                                                                           ASB10628
C INCREMENT CASE NUMBER                                                     ASB10629
C IF CASE NUMBER EXCEEDS NMAX THEN STOP                                     ASB10630
C OTHERWISE CHECK TO SEE IF NEW PHYSICAL DATA IS TO BE READ IN              ASB10631
C                                                                           ASB10632
  716 NCASE=NCASE+1                                                         ASB10633
      IF(NCASE.GT.NMAX) GOTO 1000                                           ASB10634
      READ(5,10) NEWPD                                                      ASB10635
      IF(NEWPD.NE.1) GOTO 42                                                ASB10636
      WRITE(6,43) NCASE                                                     ASB10637
      GOTO 1                                                                ASB10638
 1000 CONTINUE                                                              ASB10639
C ************************************************************************  ASB10640
C *  MAIN PROGRAM FORMAT STATEMENTS (INPUT FIRST OUTPUT SECOND)  *          ASB10641
C ************************************************************************  ASB10642
   10 FORMAT(I1)                                                            ASB10643
   20 FORMAT(I3)                                                            ASB10644
   30 FORMAT(F10.0)                                                         ASB10645
   40 FORMAT(F10.0,F10.0)                                                   ASB10646
   50 FORMAT(F10.0,F10.0,F10.0)                                             ASB10647
   60 FORMAT(A10,F10.0,F10.0)                                               ASB10648
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 70 FORMAT(A10,F10.0)                                                    ASB10649
 80 FORMAT(F10.0,F10.0,F10.0,F10.0)                                      ASB10650
 43 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,58X,            ASB10651
   1'CASE NUMBER ',I3)                                                   ASB10652
105 FORMAT(' ',/,/,/,/,/,/,/,47X,'NUMBER OF ',A7,' DATA POINTS = ',      ASB10653
   1I3,/,/,/,/,44X,                                                      ASB10654
   2'THIS NUMBER MUST BE REDUCED TO ',I3,' OR LESS;',/,/,41X,            ASB10655
   3'OTHERWISE THE ',A7,' ARRAYS MUST BE REDIMENSIONED')                 ASB10656
475 FORMAT('1',12X,'STEP',34X,'FORCES',40X,'OVERTURNING MOMENTS',        ASB10657
   1/,11X,                                                               ASB10658
   2'NUMBER',11X,'X DIRECTION',11X,'Y DIRECTION',11X,'TOTAL',11X,        ASB10659
   3'X DIRECTION',11X,'Y DIRECTION')                                     ASB10660
485 FORMAT('0',13X,I3,12X,F11.3,11X,F11.3,8X,F11.3,8X,F11.3,11X,        ASB10661
   1F11.3)                                                               ASB10662
505 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,48X,                           ASB10663
   1'BUOY ORIENTS ITSELF WITH THE CURRENT',/,/,/,47X,                    ASB10664
   2'BUOY BEARING = ',F6.2,' DEGREES MAGNETIC')                          ASB10665
515 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,46X,                           ASB10666
   1'BUOY ORIENTS ITSELF WITH THE WIND',/,/,/,47X,                       ASB10667
   2'BUOY BEARING = ',F6.2,' DEGREES MAGNETIC')                          ASB10668
525 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,53X,                           ASB10669
   1'NO CURRENT OR WIND PRESENT',/,/,/,41X,                              ASB10670
   2'BUOY BEARING SET EQUAL TO ',F6.2,                                   ASB10671
   3' DEGREES MAGNETIC')                                                 ASB10672
605 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,58X,                           ASB10673
   1'*** RESULTS ***',/,/,50X,                                           ASB10674
   2'AVERAGE CURRENT VELOCITY = ',F5.2,/,/,49X,                          ASB10675
   3'AVERAGE CURRENT DIRECTION = ',F5.1,/,/,43X,                         ASB10676
   4'AVERAGE CURRENT ANGLE OF ATTACK = ',F6.1,/,/,55X,                   ASB10677
   5'WAVE AMPLITUDE = ',F5.2,/,/,60X,                                    ASB10678
   6'ICOUNT = ',I3,/,/,/,59X,                                            ASB10679
   7'X - DIRECTION',/,/,40X,                                             ASB10680
   8'LIST ANGLE = ',16X,F7.3,' DEGREES',/,/,40X,                         ASB10681
   9'OVERTURNING MOMENT = ',2X,F12.2,' FT. - LBS.',/,/,40X,              ASB10682
   X'RIGHTING MOMENT = ',5X,F12.2,' FT. - LBS.',/,/,/,59X,               ASB10683
   1'Y - DIRECTION',/,/,40X,                                             ASB10684
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     2'LIST ANGLE = ',16X,F7.3,' DEGREES',/,/,40X,                      ASB10685
     3'OVERTURNING MOMENT = ',2X,F12.2,' FT. - LBS.',/,/,40X,           ASB10686
     4'RIGHTING MOMENT = ',5X,F12.2,' FT. - LBS.'/,/,40X,               ASB10687
     5'WATCH CIRCLE RADIUS = ',1X,F12.2,' FEET',/,/,40X,                ASB10688
     6'SPAR BUOY LIST ANGLE = ',6X,F7.3,' DEGREES')                     ASB10689
 615 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,58X,                          ASB10690
     1'*** RESULTS ***',/,/,50X,                                        ASB10691
     2'AVERAGE CURRENT VELOCITY = ',F5.2,/,/,49X,                       ASB10692
     3'AVERAGE CURRENT DIRECTION = ',F5.1,/,/,43X,                      ASB10693
     4'AVERAGE CURRENT ANGLE OF ATTACK = ',F5.1,/,/,55X,                ASB10694
     5'WAVE AMPLITUDE = ',F5.2,/,/,60X,                                 ASB10695
     6'ICOUNT = ',I3,/,/,/,51X,                                         ASB10696
     7'SPAR BUOY COMPLETELY SUBMERGED',/,/,/,49X,                       ASB10697
     8'SPAR LENGTH',27X,F7.3,'  FEET',/,/,40X,                          ASB10698
     9'X - DIRECTION LIST ANGLE',14X,F7.3,'  DEGREES',/,/,40X,          ASB10699
     1'Y - DIRECTION LIST ANGLE',14X,F7.3,'  DEGREES',/,/,40X,          ASB10700
     2'PROJECTED SPAR LENGTH',17X,F7.3,'  FEET',/,/,40X,                ASB10701
     3'MEAN WATER DEPTH',22X,F7.3,'  FEET',/,/,40X,                     ASB10702
     4'TOTAL WATER DEPTH',21X,F7.3,'  FEET')                            ASB10703
      RETURN                                                            ASB10704
      END                                                               ASB10705
C ****************************************************************    ASB10706
C *                      SUBROUTINE WEIGHT                       *    ASB10707
C ****************************************************************    ASB10708
      SUBROUTINE WEIGHT(SPL,SPW,SPD,SWT,SMD,VL,VW,VT,VMD,               ASB10709
     1IART,CIRCUM,SWGT,VWGT,TSWGT,CAREA,VMWWD)                          ASB10710
C                                                                       ASB10711
C THIS SUBROUTINE CALCULATES THE WEIGHT OF THE SPAR BUOY IN AIR AND     ASB10712
C ITS BUOYANT WEIGHT IN WATER.  IF THE SPAR BUOY IS ARTICULATED THEN    ASB10713
C A CHECK IS MADE TO DETERMINE IF AS A FREE FLOATING BODY IT HAS        ASB10714
C SUFFICIENT BUOYANCY TO FLOAT                                          ASB10715
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY           ASB10716
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB10717
C                                                                       ASB10718
C CALCULATE THE WEIGHT OF THE SPAR BUOY AND ORIENTING VANE              ASB10719
C IN AIR                                                                ASB10720
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      W=SPW/2.0                                                          ASB10721
      D=SPD/2.0                                                          ASB10722
      CM=(W-D)/(W+D)                                                     ASB10723
      CK=1.0+0.25*CM**2.+1.0/64.0*CM**4.+1.0/256.0*CM**6.                ASB10724
      CIRCUM=PI*(D+W)*CK                                                 ASB10725
      CAREA=D*W*PI                                                       ASB10726
      SWGT=CIRCUM*SPL*SWT*SMD*G                                          ASB10727
      IF(SWT.EQ.0.0) SWGT=CAREA*SPL*SMD*G                                ASB10728
      VWGT=VW*VL*VT*VMD*G                                                ASB10729
      TSWGT=SWGT+VWGT                                                    ASB10730
C                                                                        ASB10731
C CALCULATE THE WEIGHT OF THE WATER DISPLACED BY THE SPAR BUOY           ASB10732
      SWWD=CAREA*SPL*RWAT*G                                              ASB10733
      VMWWD=VW*VL*VT*RWAT*G                                              ASB10734
      TBWGT=SWWD+VMWWD                                                   ASB10735
      IF(IART.NE.1) GOTO 200                                             ASB10736
C                                                                        ASB10737
C IF BUOY IS ARTICULATED CHECK TO SEE IF AS A FREE FLOATING BODY IT      ASB10738
C HAS SUFFICIENT BUOYANCY TO FLOAT                                       ASB10739
      IF(TBWGT.LT.TSWGT) GOTO 100                                        ASB10740
      GOTO 200                                                           ASB10741
  100 WRITE(6,5) TBWGT,TSWGT                                             ASB10742
    5 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,51X,  ASB10743
     1'BUOYANT FORCE = ',F8.2,' LBS.',/,/,50X,                           ASB10744
     2'WEIGHT OF SPAR = ',F8.2,' LBS.',/,/,/,/,/,/,/,42X,                ASB10745
     3'*****   THIS BUOY DESIGN WILL NOT FLOAT   *****')                  ASB10746
      STOP                                                               ASB10747
  200 RETURN                                                             ASB10748
      END                                                                ASB10749
C ***************************************************************        ASB10750
C *            SUBROUTINE WNDSPD(W10,ELEV,NPTS,WSPD)            *        ASB10751
C ***************************************************************        ASB10752
      SUBROUTINE WNDSPD(W10,ELEV,NPTS,WSPD)                              ASB10753
C                                                                        ASB10754
C THIS SUBROUTINE TAKES THE WIND SPEED AT THE 10 METER LEVEL, W10,       ASB10755
C AND AN ELEVATION ARRAY, ELEV(NPTS) WHICH CONTAINS THE ELEVATION        ASB10756
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C IN METERS FOR WHICH THE WIND VELOCITY IS DESIRED.  A WIND SPEED          ASB10757
C ARRAY, WSPD(NPTS) CONTAINING THE WIND VELOCITY VALUES BASED UPON         ASB10758
C A LOGRITHIMIC DISTRIBUTION IS RETURNED                                   ASB10759
C                                                                          ASB10760
      DIMENSION ELEV(NPTS),WSPD(NPTS)                                      ASB10761
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY               ASB10762
      COMMON NWDP,NCDP,NWADP,NWPDP                                         ASB10763
      ZO=3.0E-03                                                           ASB10764
      DO 100 I=1,NPTS                                                      ASB10765
  100 WSPD(I)=(ALOG(ELEV(I)/ZO)/ALOG(10./ZO))*W10                          ASB10766
      RETURN                                                               ASB10767
      END                                                                  ASB10768
C ***********************************************************              ASB10769
C *                    SUBROUTINE WAVSMB                    *              ASB10770
C ***********************************************************              ASB10771
      SUBROUTINE WAVSMB(WSPD,FETCH,TSIG,TAVG,HGTSIG,HGTAVG)                ASB10772
C                                                                          ASB10773
C SUBROUTINE WAVSMB CALCULATES THE SIGNIFICANT WAVE HEIGHT AND             ASB10774
C SIGNIFICANT PERIOD OF A WAVE FIELD AS WELL AS THE AVERAGE WAVE           ASB10775
C HEIGHT AND AVERAGE WAVE PERIOD UNDER SPECIFIED WIND, FETCH               ASB10776
C AND DEPTH CONDITIONS USING THE SMB METHOD.                               ASB10777
C                                                                          ASB10778
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY               ASB10779
      COMMON NWDP,NCDP,NWADP,NWPDP                                         ASB10780
      A=G*FETCH/(WSPD**2)                                                  ASB10781
      B=G*DEPTH/(WSPD**2)                                                  ASB10782
C                                                                          ASB10783
C COMPUTE SIGNIFICANT AND AVERAGE WAVE HEIGHTS                             ASB10784
      HGTSIG=0.283*TANH(0.530*B**0.75)*TANH((0.0125*A**0.42)/(TANH         ASB10785
     1(0.530*B**0.75)))*WSPD**2/G                                          ASB10786
      HGTAVG=0.6257*HGTSIG                                                 ASB10787
C                                                                          ASB10788
C COMPUTE SIGNIFICANT AND AVERAGE WAVE PERIODS                             ASB10789
      TSIG=1.20*TANH(0.833*B**0.375)*TANH((0.077*A**0.25)/                 ASB10790
     1(TANH(0.833*B**0.375)))*2*PI*WSPD/G                                  ASB10791
      TAVG=SQRT(HGTSIG/0.45)                                               ASB10792
```

```
      RETURN                                                            ASB10793
      END                                                               ASB10794
C ***********************************************************************ASB10795
C *                          SUBROUTINE WAVE                            *ASB10796
C ***********************************************************************ASB10797
      SUBROUTINE WAVE(TSIG,TAVG,HGTSIG,HGTAVG,NWHPTS,ITHERY,WVNO,       ASB10798
     XSIG,WAMP,C,DELTAT,WA)                                             ASB10799
C                                                                       ASB10800
C SUBROUTINE WAVE COMPUTES INFORMATION ABOUT A WAVE USING EITHER        ASB10801
C LINEAR (AIRY) OR STOKES SECOND ORDER WAVE THEORY.                     ASB10802
C                                                                       ASB10803
      DIMENSION WA(100)                                                 ASB10804
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB10805
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB10806
      REAL LENGTI,M,NEWL                                                ASB10807
C                                                                       ASB10808
C COMPUTE THE DEEP WATER WAVELENGTH, DLO                                ASB10809
      DLO=G*TAVG**2./(2*PI)                                             ASB10810
      HOLO=DEPTH/DLO                                                    ASB10811
C                                                                       ASB10812
C DETERMINE THE RANGE OF H OVER L AND CALCULATE H/L                     ASB10813
      IF(HOLO.LT.0.04) GOTO 10                                          ASB10814
      IF(HOLO.LT.0.15) GOTO 20                                          ASB10815
      IF(HOLO.LT.0.39) GOTO 30                                          ASB10816
      HL=HOLO                                                           ASB10817
      GOTO 100                                                          ASB10818
   10 A=0.43                                                            ASB10819
      M=0.511                                                           ASB10820
      GOTO 40                                                           ASB10821
   20 A=0.54                                                            ASB10822
      M=0.580                                                           ASB10823
      GOTO 40                                                           ASB10824
   30 A=0.83                                                            ASB10825
      M=0.808                                                           ASB10826
   40 HL=A*HOLO**M                                                      ASB10827
  100 NEWL=DEPTH/HL                                                     ASB10828
```

```
C                                                                       ASB10829
C  ITERATE TO IMPROVE ESTIMATE                                          ASB10830
       WL=DLO*TANH(2*PI*DEPTH/NEWL)                                     ASB10831
       DO 200 K=1,500                                                   ASB10832
       LENGTI=WL                                                        ASB10833
       WL=DLO*TANH(2*PI*DEPTH/LENGTI)                                   ASB10834
       IF(0.001*LENGTI.GE.ABS(LENGTI-WL)) GOTO 300                      ASB10835
   200 CONTINUE                                                         ASB10836
C                                                                       ASB10837
C  COMPLETION OF THE ABOVE DO LOOP INDICATES AN ERROR IN                ASB10838
C  THE WAVELENGTH CALCULATION.   CHECK RESULTS                          ASB10839
       WRITE(6,250)  NEWL,WL,LENGTI,TAVG,DEPTH                          ASB10840
       GOTO 1000                                                        ASB10841
C                                                                       ASB10842
C  CHECK THE RATIO OF WAVE HEIGHT TO WAVE LENGTH FOR                    ASB10843
C  EXCESSIVE STEEPNESS                                                  ASB10844
   300 R1=HGTAVG/WL                                                     ASB10845
       IF(0.142*WL/DLO.LE.R1) GOTO 400                                  ASB10846
C                                                                       ASB10847
C  COMPUTE WAVE CELERITY, WAVE FREQUENCY, WAVE NUMBER AND               ASB10848
C  MAXIMUM WAVE AMPLITUDE                                               ASB10849
       WVNO=2.0*PI/WL                                                   ASB10850
       SIG=2.0*PI/TAVG                                                  ASB10851
       C=G/SIG*TANH(2.*PI*DEPTH/WL)                                     ASB10852
       WAMP=HGTAVG/2.0                                                  ASB10853
       DELTAT=TAVG/(NWHPTS-1)                                           ASB10854
C                                                                       ASB10855
C  COMPUTE THE WAVE AMPLITUDE ARRAY                                     ASB10856
       DO 500 I=1,NWHPTS                                                ASB10857
   500 WA(I)=HGTAVG/2.0*COS(SIG*DELTAT*(I-1))                           ASB10858
       IF(ITHERY.EQ.2)  WA(I)=WA(I)+(WAMP**2.*WVNO/2.*                  ASB10859
      1COSH(2.*PI*DEPTH/WL)/SINH(2.*PI*DEPTH/WL) **3.*COS(-2.*SIGMAT))  ASB10860
       WRITE(6,550)  HGTSIG,HGTAVG,TSIG,TAVG,WL,C,WVNO,SIG,DELTAT       ASB10861
       DO 600 I=1,NWHPTS                                                ASB10862
   600 WRITE(6,650)  I,WA(I)                                            ASB10863
   650 FORMAT('0',40X,I3,31X,F5.2)                                      ASB10864
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```
      GOTO 1000                                                          ASB10865
  400 WRITE(6,450)  HGTAVG,WL,R1                                         ASB10866
      GOTO 1000                                                          ASB10867
C *****************************************************************    ASB10868
C *                  SUBROUTINE WAVE FORMAT STATEMENTS              *  ASB10869
C *****************************************************************    ASB10870
  250 FORMAT('1',/,/,/,/,/,/,52X,                                        ASB10871
     1'ERROR IN SUBROUTINE WAVE',/,/,/,55X,                              ASB10872
     2'NEWL = ',6X,F9.3,/,/,55X,                                         ASB10873
     3'WAVELENGTH = ',F9.3,/,/,55X,                                      ASB10874
     4'LENGTI = ',4X,F9.3,/,/,55X,                                       ASB10875
     5'TAVG = ',6X,F9.3,/,/,55X,                                         ASB10876
     6'DEPTH = ',5X,F9.3)                                                ASB10877
  450 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,59X,                            ASB10878
     1'WAVE TOO STEEP',/,/,/,54X,                                        ASB10879
     2'WAVE HEIGHT = ',F6.2,' FEET',/,/,54X,                             ASB10880
     3'WAVE LENGTH = ',F6.2,' FEET',/,/,53X,                             ASB10881
     4'H OVER L = ',F5.4)                                                ASB10882
  550 FORMAT('1',/,/,58X,'WAVE INFORMATION',/,/,/,40X,                   ASB10883
     1'SIGNIFICANT WAVE HEIGHT',16X,F6.3,'  FEET',/,/,40X,               ASB10884
     2'AVERAGE WAVE HEIGHT',20X,F6.3,'  FEET',/,/,40X,                   ASB10885
     3'SIGNIFICANT WAVE PERIOD',16X,F6.3,'  SECONDS',/,/,40X,            ASB10886
     4'AVERAGE WAVE PERIOD',20X,F6.3,'  SECONDS',/,/,40X,                ASB10887
     5'WAVELENGTH (AFTER WEIGAL)',13X,F7.3,'  FEET',/,/,40X,             ASB10888
     6'WAVE CELERITY',26X,F6.3,'  FEET',/,/,40X,                         ASB10889
     7'WAVE NUMBER',28X,F6.3,'  1/FEET',/,/,40X,                         ASB10890
     8'ANGULAR WAVE FREQUENCY',17X,F6.3,'  RADIANS/SEC.',/,/,40X,        ASB10891
     9'TIME STEP INCREMENT',20X,F6.3,'  SECONDS',/,/,/,/,/,54X,          ASB10892
     X' WAVE HEIGHT INFORMATION',/,/,38X,                                ASB10893
     1'TIME STEP',25X,'WAVE HEIGHT',/,74X,'(FEET)')                      ASB10894
 1000 RETURN                                                             ASB10895
      END                                                                ASB10896
C *****************************************************************    ASB10897
C *                        SUBROUTINE AREAS                       *    ASB10898
C *****************************************************************    ASB10899
      SUBROUTINE AREAS(SPL,SPD,SPW,EWAX,EWAY,                            ASB10900
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     1ECAX,ECAY,EWAAX,EWAAY)                                              ASB10901
C                                                                         ASB10902
C THIS SUBROUTINE DETERMINES THE SIZE  OF THE ELEMENTAL                   ASB10903
C AREAS UPON WHICH THE WIND, CURRENT AND WAVE FORCES ACT.                 ASB10904
C NOTE THAT THE WAVE AREA IS DETERMINED SOLELY FROM THE WATER             ASB10905
C DEPTH AND NOT FROM THE WATER DEPTH PLUS THE WAVE HEIGHT.                ASB10906
C THIS WAS DONE TO SIMPLIFY THE WAVE FORCE CALCULATION                    ASB10907
C WITHOUI INTRODUCING ANY SIGNIFICANT ERROR.                              ASB10908
C                                                                         ASB10909
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY              ASB10910
      COMMON NWDP,NCDP,NWADP,NWPDP                                        ASB10911
C                                                                         ASB10912
C CALCULATE PROJECTED CURRENT AND WAVE SPAR LENGTHS                       ASB10913
      PSPLX=DEPTH/COS(AOLY*PI/180.)                                       ASB10914
      PSPLY=DEPTH/COS(AOLX*PI/180.)                                       ASB10915
C                                                                         ASB10916
C CALCULATE PROJECTED WIND SPAR LENGTHS                                   ASB10917
      TSPLX=SPL-PSPLX                                                     ASB10918
      TSPLY=SPL-PSPLY                                                     ASB10919
C                                                                         ASB10920
C CALCULATE ELEMENTAL WIND AREAS                                          ASB10921
      IF(NWDP.NE.0) GOTO 10                                               ASB10922
      EWAX=0.0                                                            ASB10923
      EWAY=0.0                                                            ASB10924
      GOTO 20                                                             ASB10925
   10 EWAX=TSPLX/(FLOAT(NWDP))*SPD                                        ASB10926
      EWAY=TSPLY/(FLOAT(NWDP))*SPW                                        ASB10927
C                                                                         ASB10928
C CALCULATE ELEMENTAL CURRENT AREAS                                       ASB10929
   20 IF(NCDP.NE.0) GOTO 30                                               ASB10930
      ECAX=0.0                                                            ASB10931
      ECAY=0.0                                                            ASB10932
      GOTO 40                                                             ASB10933
   30 ECAY=PSPLX/(FLOAT(NCDP))*SPD                                        ASB10934
      ECAY=PSPLY/(FLOAT(NCDP))*SPW                                        ASB10935
C                                                                         ASB10936
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```
C CALCULATE ELEMENTAL WAVE AREAS                                        ASB10937
   40 IF(NWADP.NE.0) GOTO 50                                            ASB10938
      EWAAX=0.0                                                         ASB10939
      EWAAY=0.0                                                         ASB10940
      GOTO 60                                                           ASB10941
   50 EWAAX=PSPLX/(FLOAT(NWADP))*SPD                                    ASB10942
      EWAAY=PSPLY/(FLOAT(NWADP))*SPW                                    ASB10943
   60 CONTINUE                                                          ASB10944
      RETURN                                                            ASB10945
      END                                                               ASB10946
C *****************************************************************   ASB10947
C *                        SUBROUTINE CBEAR                       *   ASB10948
C *****************************************************************   ASB10949
      SUBROUTINE CBEAR(VEL,DIR,DEP,VL,VW,VHGT,DIRV,BEAR)                ASB10950
C                                                                       ASB10951
C IF THERE IS A CURRENT PRESENT AND THE SPAR BUOY HAS AN ORIENTING      ASB10952
C VANE, SUBROUTINE CBEAR DETERMINES THE BEARING OF THE BUOY             ASB10953
C RELATIVE TO MAGNETIC NORTH BY FINDING THROUGH LINEAR                  ASB10954
C INTERPOLATION, THE CURRENT DIRECTION AT THE CENTROID                  ASB10955
C OF THE VANE.                                                          ASB10956
C                                                                       ASB10957
      DIMENSION VEL(501),DIR(501),DEP(501)                              ASB10958
      DIMENSION CDIR(501)                                               ASB10959
      DIMENSION CVX(500),CVY(500)                                       ASB10960
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB10961
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB10962
      NCDPT=NCDP+1                                                      ASB10963
C                                                                       ASB10964
C COMPUTE THE TOTAL VANE ELEVATION, THE VANE WIDTH                      ASB10965
C CORRECTION FACTOR AND CHECK TO SEE IF THE TOP OF                      ASB10966
C THE VANE IS UNDERWATER.                                               ASB10967
      TVE=(VHGT+VL)*COS(AOLX*PI/180.)*COS(AOLY*PI/180.)                 ASB10968
      VWCF=(VW/2.0)*SIN(AOLX*PI/180.)*SIN(AOLY*PI/180.)*                ASB10969
     1COS(AOLX*PI/180.)*COS(AOLY*PI/180.)                               ASB10970
      IF(TVE.GE.DEPTH) GOTO 50                                          ASB10971
      VD=DEPTH-((VHGT+VL/2.0)*COS(AOLX*PI/180.)*COS(AOLY*PI/180.))+     ASB10972
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```
     1VWCF                                                                    ASB10973
      GOTO 60                                                                 ASB10974
   50 VD=(DEPTH-VHGT*COS(AOLX*PI/180.)*COS(AOLY*PI/180.))/2.0+VWCF            ASB10975
   60 CONTINUE                                                               ASB10976
C     WRITE(6,7777) VD,DEP                                                   ASB10977
C7777 FORMAT(' ',10(2X,F9.4))                                                ASB10978
C                                                                            ASB10979
C DETERMINE BY LINEAR INTERPOLATION THE CURRENT VELOCITY                     ASB10980
C AT THE ORIENTING VANE                                                      ASB10981
      DO 100 I=2,NCDPT                                                       ASB10982
      IF(DEP(I).GE.VD) GOTO 200                                              ASB10983
  100 CONTINUE                                                               ASB10984
  200 DELTD=DEP(I)-DEP(I-1)                                                  ASB10985
      DELTV=DEP(I)-VD                                                        ASB10986
      PCT=DELTV/DELTD                                                        ASB10987
      IN=I                                                                   ASB10988
      IM=I-1                                                                 ASB10989
C                                                                            ASB10990
C COMPUTE CURRENT VELOCITIES AT THE ORIENTING VANE                           ASB10991
      DO 300 J=IM,IN                                                         ASB10992
      CVX(J)=VEL(J)*COS(DIR(J)*PI/180.)                                      ASB10993
  300 CVY(J)=VEL(J)*SIN(DIR(J)*PI/180.)                                      ASB10994
C                                                                            ASB10995
      DLTVX=CVX(IN)-CVX(IM)                                                  ASB10996
      DLTVY=CVY(IN)-CVY(IM)                                                  ASB10997
      CVXV=CVX(IN)-PCT*DLTVX                                                 ASB10998
      CVYV=CVY(IN)-PCT*DLTVY                                                 ASB10999
      IF((CVXV.LE.0.001).AND.(CVXV.GE.-0.001)) GOTO 500                      ASB11000
      DIRV=ATAN(CVYV/CVXV)*180./PI                                           ASB11001
      IF(CVXV.LT.0.00) DIRV=DIRV+180.                                        ASB11002
      GOTO 600                                                               ASB11003
  500 IF(CVYV.GE.0.00) DIRV=90.00                                            ASB11004
      IF(CVYV.LT.0.00) DIRV=-90.00                                           ASB11005
C                                                                            ASB11006
C CONVERT BACK TO COMPASS DIRECTION                                          ASB11007
  600 SBEAR=DIRV                                                             ASB11008
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      BEAR=SBEAR+180.                                                    ASB11009
      IF(BEAR.GT.360.) BEAR=BEAR-360.                                    ASB11010
      RETURN                                                             ASB11011
      END                                                                ASB11012
C *****************************************************************     ASB11013
C *                        SUBROUTINE RWVEL                       *     ASB11014
C *****************************************************************     ASB11015
      SUBROUTINE RWVEL(BEAR,PSPLAW,WSPD,WDIR,ELEV,                       ASB11016
     1WAA,WSP,WVELX,WVELNX,WVELY,WVELNY)                                 ASB11017
C                                                                        ASB11018
C SUBROUTINE RWVEL CALCULATES THE WIND  VELOCITIES NORMAL                ASB11019
C TO THE SPAR IN THE X AND Y DIRECTIONS.                                 ASB11020
C                                                                        ASB11021
      DIMENSION ELEV(100),Z(100),WSP(100)                                ASB11022
      DIMENSION WVELX(100),WVELY(100),WVELNX(100),WVELNY(100)            ASB11023
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY             ASB11024
      COMMON NWDP,NCDP,NWADP,NWPDP                                       ASB11025
C                                                                        ASB11026
C DETERMINE ANGLE OF ATTACK                                              ASB11027
      WAA=BEAR-WDIR                                                      ASB11028
      IF(WAA.GT.180.0) WAA=360.-WAA                                      ASB11029
      IF(WAA.LT.-180.0) WAA=360.+WAA                                     ASB11030
      CFPM=0.3048                                                        ASB11031
C                                                                        ASB11032
C DETERMINE ELEVATION FROM THE WATER SURFACE TO THE                      ASB11033
C CENTER OF THE WIND AREA                                                ASB11034
      DO 100 I=1,NWDP                                                    ASB11035
      ELEV(I)=PSPLAW/FLOAT(NWDP)*FLOAT(I)-PSPLAW/(2.*FLOAT(NWDP))        ASB11036
  100 Z(I)=ELEV(I)*CFPM                                                  ASB11037
C                                                                        ASB11038
C COMPUTE THE WIND SPEED AT ANY HEIGHT USING A LOGRITHMIC                ASB11039
C PROFILE AND A KNOWN VELOCITY AT THE 10 METER LEVEL.                    ASB11040
      CALL WNDSPD(WSPD,Z,NWDP,WSP)                                       ASB11041
C                                                                        ASB11042
C DETERMINE WIND VELOCITIES RELATIVE TO THE SPAR BUOY                    ASB11043
C ORIENTATION IN THE X-Y PLANE                                           ASB11044
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      DO 300 I=1,NWDP                                                    ASB11045
      WVELX(I)=WSP(I)*COS(WAA*PI/180.)                                   ASB11046
  300 WVELY(I)=WSP(I)*SIN(WAA*PI/180.)                                   ASB11047
C                                                                        ASB11048
C COMPUTE VELOCITIES NORMAL TO THE BUOY IN                               ASB11049
C THE X AND Y DIRECTIONS                                                 ASB11050
      DO 400 I=1,NWDP                                                    ASB11051
      WVELNX(I)=WVELX(I)*COS(AOLX*PI/180.)                               ASB11052
  400 WVELNY(I)=WVELY(I)*COS(AOLY*PI/180.)                               ASB11053
      RETURN                                                             ASB11054
      END                                                                ASB11055
C ***************************************************************      ASB11056
C *                        SUBROUTINE RCVEL                         *    ASB11057
C ***************************************************************      ASB11058
      SUBROUTINE RCVEL(BEAR,DIR,VEL,CAA,DEPC,CVX,CVY,CVNX,               ASB11059
     1CVNY)                                                              ASB11060
C                                                                        ASB11061
C SUBROUTINE RCVEL CALCULATES THE CURRENT VELOCITIES NORMAL              ASB11062
C TO THE SPAR IN THE X AND Y DIRECTIONS.                                 ASB11063
C                                                                        ASB11064
      DIMENSION DIR(501),VEL(501)                                        ASB11065
      DIMENSION CAA(501),DEPC(500)                                       ASB11066
      DIMENSION CVX(500),CVY(500),CVNX(500),CVNY(500)                    ASB11067
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY             ASB11068
      COMMON NWDP,NCDP,NWADP,NWPDP                                       ASB11069
      NCDPT=NCDP+1                                                       ASB11070
      SBEAR=BEAR-180.                                                    ASB11071
C                                                                        ASB11072
C DETERMINE CURRENT ANGLES OF ATTACK                                     ASB11073
      DO 100 I=1,NCDPT                                                   ASB11074
      CAA(I)=SBEAR-DIR(I)                                                ASB11075
      IF(CAA(I).GT.180.0) CAA(I)=360.-CAA(I)                             ASB11076
      IF(CAA(I).LT.-180.0) CAA(I)=360.+CAA(I)                            ASB11077
  100 CONTINUE                                                           ASB11078
C                                                                        ASB11079
C COMPUTE AVERAGE (CENTER) CURRENT VELOCITIES RELATIVE TO                ASB11080
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C THE SPAR BUOY ORIENTATION IN THE X-Y PLANE                                    ASB11081
      DO 200 I=1,NCDP                                                           ASB11082
      CVX(I)=(VEL(I)*COS(CAA(I)*PI/180.)+VEL(I+1)*                              ASB11083
     1COS(CAA(I+1)*PI/180.))/2.0                                                ASB11084
      CVY(I)=(VEL(I)*SIN(CAA(I)*PI/180.)+VEL(I+1)*                              ASB11085
     1SIN(CAA(I+1)*PI/180.))/2.0                                                ASB11086
  200 DEPC(I)=DEPTH/FLOAT(NCDP)*FLOAT(I)-DEPTH/(2.*FLOAT(NCDP))                 ASB11087
C                                                                               ASB11088
C COMPUTE CURRENT VELOCITIES NORMAL TO THE BUOY IN                              ASB11089
C THE X AND Y DIRECTIONS                                                        ASB11090
      DO 300 I=1,NCDP                                                           ASB11091
      CVNX(I)=CVX(I)*COS(AOLX*PI/180.)                                          ASB11092
  300 CVNY(I)=CVY(I)*COS(AOLY*PI/180.)                                          ASB11093
      RETURN                                                                    ASB11094
      END                                                                       ASB11095
C *****************************************************************           ASB11096
C *                        SUBROUTINE RWAVA                       *           ASB11097
C *****************************************************************           ASB11098
      SUBROUTINE RWAVA(NWADPT,ITHERY,DELTAT,WAMP,SIG,N,WVNO,                    ASB11099
     1WAA,C,HWAVX,HWAVY,VWAVX,VWAVY,WAVNX,WAVNY,WAANX,WAANY)                    ASB11100
C                                                                               ASB11101
C SUBROUTINE RWAVA COMPUTES THE WAVE PARTICLE VELOCITIES AND                    ASB11102
C ACCELERATIONS NORMAL TO THE SPAR IN THE X AND Y DIRECTIONS                    ASB11103
C USING EITHER LINEAR (AIRY) WAVE THEORY OR STOKES SECOND                       ASB11104
C ORDER WAVE THEORY.                                                            ASB11105
C                                                                               ASB11106
      DIMENSION Z(501),DEP(500),HYP1(501),HYP2(501),HYP3(501),                  ASB11107
     1HYP4(501)                                                                 ASB11108
      DIMENSION HWAVX(500),HWAVY(500),VWAVX(500),VWAVY(500)                     ASB11109
      DIMENSION WAVNX(500),WAVNY(500)                                           ASB11110
      DIMENSION HWAAX(500),HWAAY(500),VWAAX(500),VWAAY(500)                     ASB11111
      DIMENSION WAANX(500),WAANY(500)                                           ASB11112
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY                    ASB11113
      COMMON NWDP,NCDP,NWADP,NWPDP                                              ASB11114
C                                                                               ASB11115
      T1=COS(WAA*PI/180.)                                                       ASB11116
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      T2=SIN(WAA*PI/180.)                                                    ASB11117
      SIGMAT=SIG*DELTAT*N                                                    ASB11118
C                                                                            ASB11119
C COMPUTE DEPTH'S OF INTEREST                                                ASB11120
C NOTE THAT Z HAS ITS ORIGIN AT THE STILL WATER SURFACE                      ASB11121
      DO 100 I=1,NWADPT                                                      ASB11122
      T=FLOAT(I-1)                                                           ASB11123
      Z(I)=DEPTH/FLOAT(NWADP)*T*(-1.00)                                      ASB11124
C                                                                            ASB11125
C CHECK TO SEE IF THE DEPTH OF INTEREST IS ABOVE THE WATER SURFACE           ASB11126
      IF(WAMP.LE.Z(I)) GOTO 50                                               ASB11127
      HYP1(I)=COSH(WVNO*(DEPTH+Z(I)))/COSH(WVNO*DEPTH)                       ASB11128
      HYP2(I)=SINH(WVNO*(DEPTH+Z(I)))/COSH(WVNO*DEPTH)                       ASB11129
      HYP3(I)=COSH(2.*WVNO*(DEPTH+Z(I)))/(SINH(WVNO*DEPTH)**4.)              ASB11130
      HYP4(I)=SINH(2.*WVNO*(DEPTH+Z(I)))/(SINH(WVNO*DEPTH)**4.)              ASB11131
      GOTO 100                                                               ASB11132
   50 HYP1(I)=0.0                                                            ASB11133
      HYP2(I)=0.0                                                            ASB11134
      HYP3(I)=0.0                                                            ASB11135
      HYP4(I)=0.0                                                            ASB11136
  100 CONTINUE                                                               ASB11137
C                                                                            ASB11138
C CALCULATE HORIZONTAL AND VERTICAL VELOCITIES USING LINEAR (AIRY)           ASB11139
C WAVE THEORY AT THE TOP AND BOTTOM OF EACH ELEMENTAL AREA AND               ASB11140
C AVERAGE TO GET THE MEAN VELOCITY AT THE CENTER OF EACH                     ASB11141
C ELEMENTAL AREA                                                             ASB11142
      DO 200 I=1,NWADP                                                       ASB11143
      DEP(I)=DEPTH/FLOAT(NWADP)*FLOAT(I)-DEPTH/(2.*FLOAT(NWADP))            ASB11144
      HWAVX(I)=WAMP*G*WVNO/SIG*((HYP1(I)+HYP1(I+1))/2.0)*T1                  ASB11145
     1*COS(-SIGMAT)                                                          ASB11146
      HWAVY(I)=WAMP*G*WVNO/SIG*((HYP1(I)+HYP1(I+1))/2.0)*T2                  ASB11147
     1*COS(-SIGMAT)                                                          ASB11148
      VWAVX(I)=WAMP*G*WVNO/SIG*((HYP2(I)+HYP2(I+1))/2.0)*T1                  ASB11149
     1*SIN(-SIGMAT)                                                          ASB11150
      VWAVY(I)=WAMP*G*WVNO/SIG*((HYP2(I)+HYP2(I+1))/2.0)*T2                  ASB11151
     1*SIN(-SIGMAT)                                                          ASB11152
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C                                                                       ASB11153
C COMPUTE HORIZONTAL AND VERTICAL ACCELERATIONS USING LINEAR (AIRY)     ASB11154
C WAVE THEORY AT THE TOP AND BOTTOM OF EACH ELEMENTAL AREA AND          ASB11155
C AVERAGE TO GET THE MEAN VELOCITY AT THE CENTER OF EACH                ASB11156
C ELEMENTAL AREA                                                        ASB11157
      HWAAX(I)=HWAVX(I)*SIG*TAN(-SIGMAT)                                ASB11158
      HWAAY(I)=HWAVY(I)*SIG*TAN(-SIGMAT)                                ASB11159
      VWAAX(I)=-VWAVX(I)*SIG*COTAN(-SIGMAT)                             ASB11160
      VWAAY(I)=-VWAVY(I)*SIG*COTAN(-SIGMAT)                             ASB11161
C                                                                       ASB11162
C COMPUTE NORMAL VELOCITIES                                             ASB11163
      WAVNX(I)=HWAVX(I)*COS(AOLX*PI/180.)-VWAVX(I)*SIN(AOLX*PI/180.)    ASB11164
      WAVNY(I)=HWAVY(I)*COS(AOLY*PI/180.)-VWAVY(I)*SIN(AOLY*PI/180.)    ASB11165
C                                                                       ASB11166
C COMPUTE NORMAL ACCELERATIONS                                          ASB11167
      WAANX(I)=HWAAX(I)*COS(AOLX*PI/180.)-VWAAX(I)*SIN(AOLX*PI/180.)    ASB11168
      WAANY(I)=HWAAY(I)*COS(AOLY*PI/180.)-VWAAY(I)*SIN(AOLY*PI/180.)    ASB11169
  200 CONTINUE                                                          ASB11170
      IF(ITHEBY.EQ.1) GOTO 400                                          ASB11171
C                                                                       ASB11172
C CALCULATE HORIZONTAL AND VERTICAL VELOCITIES                          ASB11173
C AT THE TOP AND BOTTOM OF EACH ELEMENTAL AREA                          ASB11174
C AND AVERAGE TO GET THE MEAN VELOCITY AT THE                           ASB11175
C CENTER OF EACH ELEMENTAL AREA USING STOKES                            ASB11176
C SECOND ORDER WAVE THEORY                                              ASB11177
      DO 300 I=1,NWADP                                                  ASB11178
      HWAVX(I)=HWAVX(I)+0.75*(WVNO*WAMP)**2.*C*((HYP3(I)+HYP3(I+1))     ASB11179
     1/2.0)*T1*COS(-2.*SIGMAT)                                          ASB11180
      HWAVY(I)=HWAVY(I)+0.75*(WVNO*WAMP)**2.*C*((HYP3(I)+HYP3(I+1))     ASB11181
     1/2.0)*T2*COS(-2.*SIGMAT)                                          ASB11182
      VWAVX(I)=C*SIG/G*VWAVX(I)+0.75*(WVNO*WAMP)**2.*C*((HYP3(I)        ASB11183
     1+HYP3(I+1))/2.0)*T1*SIN(-2.*SIGMAT)                               ASB11184
      VWAVY(I)=C*SIG/G*VWAVY(I)+0.75*(WVNO*WAMP)**2.*C*((HYP3(I)        ASB11185
     1+HYP3(I+1))/2.0)*T2*SIN(-2.*SIGMAT)                               ASB11186
C                                                                       ASB11187
C COMPUTE HORIZONTAL AND VERTICAL ACCELERATIONS USING STOKES SECOND     ASB11188
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C ORDER WAVE THEORY AT THE TOP AND BOTTOM OF EACH ELEMENTAL AREA                ASB11189
C AND AVERAGE TO GET THE MEAN VELOCITY AT THE CENTER OF EACH                    ASB11190
C ELEMENTAL AREA                                                                ASB11191
      HWAAX(I)=HWAAX(I)+2.*SIG*0.75*(WVNO*WAMP)**2.*C*(HYP3(I)+                 ASB11192
     1HYP3(I+1))/2.0*T1*SIN(-SIGMAT)                                            ASB11193
      HWAAY(I)=HWAAY(I)+2.*SIG*0.75*(WVNO*WAMP)**2.*C*(HYP3(I)+                 ASB11194
     1HYP3(I+1))/2.0*T2*SIN(-SIGMAT)                                            ASB11195
      VWAAX(I)=C*SIG/G*VWAAX(I)-2.*SIG*0.75*(WVNO*WAMP)**2.*C*                  ASB11196
     1(HYP4(I)+HYP4(I+1))/2.0*T1*COS(-SIGMAT)                                   ASB11197
      VWAAY(I)=C*SIG/G*VWAAY(I)-2.*SIG*0.75*(WVNO*WAMP)**2.*C*                  ASB11198
     1(HYP4(I)+HYP4(I+1))/2.0*T2*COS(-SIGMAT)                                   ASB11199
C                                                                               ASB11200
C COMPUTE NORMAL VELOCITIES                                                     ASB11201
      WAVNX(I)=HWAVX(I)*COS(AOLX*PI/180.)-VWAVX(I)*SIN(AOLX*PI/180.)            ASB11202
      WAVNY(I)=HWAVY(I)*COS(AOLY*PI/180.)-VWAVY(I)*SIN(AOLY*PI/180.)            ASB11203
C                                                                               ASB11204
C COMPUTE NORMAL ACCELERATIONS                                                  ASB11205
      WAANX(I)=HWAAX(I)*COS(AOLX*PI/180.)-VWAAX(I)*SIN(AOLX*PI/180.)            ASB11206
  300 WAANY(I)=HWAAY(I)*COS(AOLY*PI/180.)-VWAAY(I)*SIN(AOLY*PI/180.)            ASB11207
  400 RETURN                                                                    ASB11208
      END                                                                       ASB11209
C *****************************************************************           ASB11210
C *                        SUBROUTINE WPV                         *           ASB11211
C *****************************************************************           ASB11212
      SUBROUTINE WPV(WAVNX,WAVNY,CVX,CVY,WPVNX,WPVNY)                           ASB11213
      DIMENSION Z(100),WAVNX(100),WAVNY(100),WPVNX(100),WPVNY(100)              ASB11214
      DIMENSION HYP1(100)                                                       ASB11215
      DIMENSION DEP(100),CVX(100),CVY(100)                                      ASB11216
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY                    ASB11217
      COMMON NWDP,NCDP,NWADP,NWPDP                                              ASB11218
      NCDPT=NCDP+1                                                              ASB11219
      DEP(I)=DEP(I-1)+(DEPTH/FLOAT(NCDP))                                       ASB11220
      NWPDP=NWADP                                                               ASB11221
      NWPDPT=NWPDP+1                                                            ASB11222
      DO 100 I=1,NWPDPT                                                         ASB11223
      T=I-1                                                                     ASB11224
```

```
      Z(I)=T*(DEPTH+WAMP)/FLOAT(NWPDP)                                  ASB11225
                                                                        ASB11226
C                                                                       ASB11227
C CHECK TO SEE IF THE DEPTH OF INTEREST IS BELOW THE STILL WATER DEPTH  ASB11228
      IF(Z(I).GE.WAMP) GOTO 200                                         ASB11229
      WPVNX(I)=WAVNX(I)                                                 ASB11230
      WPVNY(I)=WAVNY(I)                                                 ASB11231
      GOTO 100                                                          ASB11232
  200 IF(Z(I).NE.WAMP) GOTO 300                                         ASB11233
      WPVNX(I)=WAVNX(I)+CVX(1)                                          ASB11234
      WPVNY(I)=WAVNY(I)+CVY(1)                                          ASB11235
      GOTO 100                                                          ASB11236
  300 DO 400 J=2,NCDP                                                   ASB11237
      IF(DEP(J)+WAMP.GE.Z(I)) GOTO 500                                  ASB11238
  400 CONTINUE                                                          ASB11239
  500 CONTINUE                                                          ASB11240
      DEL1D= DEP(J)-DEP(J-1)                                            ASB1124.
      DEL2D=DEP(J)+WAMP-Z(I)                                            ASB11242
      DELCX=CVX(J)-CVX(J-1)                                             ASB11243
      DELCY=CVY(J)-CVY(J-1)                                             ASB11244
      PCT=DEL2D/DEL1D                                                   ASB11245
      CVELX=CVX(J)-DELCX*PCT                                            ASB11246
      CVELY=CVY(J)-DELCY*PCT                                            ASB11247
      GOTO 600                                                          ASB11248
  600 WPVNX(I)=WAVNX(I)+CVELX                                           ASB11249
      WPVNY(I)=WAVNY(I)+CVELY                                           ASB11250
  100 CONTINUE                                                          ASB11251
      Z(I)=DEPTH/FLOAT(NWADP)*T*(-1.00)                                 ASB11252
      IF(PWAMP.LE.Z(I)) GOTO 700                                        ASB11253
      HYP1(I)=COSH(WVNO*(DEPTH+Z(I)))/COSH(WVNO*DEPTH)                  ASB11254
      GOTO 800                                                          ASB11255
  700 HYP1(I)=0.0                                                       ASB11256
  800 CONTINUE                                                          ASB11257
      DO 900 I=1,NWADPT                                                 ASB11258
      WAVNX(I)=2.0*HYP1(I)                                              ASB11259
      WAVNY(I)=2.0*HYP1(I)                                              ASB11260
  900 CONTINUE
```

```
      RETURN                                                            ASB11261
      END                                                               ASB11262
C ****************************************************************     ASB11263
C *                        SUBROUTINE DRAGC                        *     ASB11264
C ****************************************************************     ASB11265
      SUBROUTINE DRAGC(WVELNX,WPVNX,SPD,PSPLAW,DEPWP,                   ASB11266
     1REW,REWP,CWD,CWPD)                                                ASB11267
C                                                                       ASB11268
C IF THE SPAR HAS A CIRCULAR CROSS-SECTION, THEN                        ASB11269
C SUBROUTINE DRAGC CALCULATES REYNOLD'S NUMBERS AND DRAG                ASB11270
C COEFFICIENTS FOR THE WIND AND WATER PARTICLE FORCES ACTING            ASB11271
C ON THE SPAR.                                                          ASB11272
C                                                                       ASB11273
      DIMENSION WVELNX(100),WPVNX(500)                                  ASB11274
      DIMENSION DEPWP(500)                                              ASB11275
      DIMENSION REW(100),REWP(500),CWD(100),CWPD(500)                   ASB11276
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB11277
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB11278
C                                                                       ASB11279
C CALCULATE WIND REYNOLDS NUMBERS                                       ASB11280
      IF(NWDP.EQ.0) GOTO 350                                            ASB11281
      DO 100 I=1,NWDP                                                   ASB11282
      REW(I)=RAIR*ABS(WVELNX(I))*SPD/UAIR                               ASB11283
      IF(REW(I).GE.5.0E05) GOTO 200                                     ASB11284
      IF(REW(I).LE.2.0E05) GOTO 300                                     ASB11285
      CWD(I)=-1.667E-06*REW(I)+1.5334                                   ASB11286
      GOTO 100                                                          ASB11287
  200 CWD(I)=0.70                                                       ASB11288
      GOTO 100                                                          ASB11289
  300 IF(REW(I).GE.10) GOTO 340                                         ASB11290
      CWD(I)=0.0                                                        ASB11291
      GOTO 100                                                          ASB11292
  340 CWD(I)=1.2                                                        ASB11293
  100 CONTINUE                                                          ASB11294
  350 IF(NWPDP.EQ.0) GOTO 700                                           ASB11295
C                                                                       ASB11296
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C CALCULATE WAVE PARTICLE REYNOLDS NUMBERS                                ASB11297
      DO 400 I=1,NWPDP                                                    ASB11298
      DEPWP(I)=DEPTH/FLOAT(NWPDP)*FLOAT(I)-DEPTH/(2.*FLOAT(NWPDP))        ASB11299
      REWP(I)=RWAT*ABS(WPVNX(I))*SPD/UWAT                                 ASB11300
      IF(REWP(I).GE.5.0E05) GOTO 500                                      ASB11301
      IF(REWP(I).LE.2.0E05) GOTO 600                                      ASB11302
      CWPD(I)=-1.667E-06*REWP(I)+1.5334                                   ASB11303
      GOTO 400                                                            ASB11304
  500 CWPD(I)=0.70                                                        ASB11305
      GOTO 400                                                            ASB11306
  600 IF(REWP(I).GE.10) GOTO 640                                          ASB11307
      CWPD(I)=0.0                                                         ASB11308
      GOTO 400                                                            ASB11309
  640 CWPD(I)=1.2                                                         ASB11310
  400 CONTINUE                                                            ASB11311
  700 RETURN                                                              ASB11312
      END                                                                 ASB11313
C *****************************************************************       ASB11314
C *                        SUBROUTINE DRAGX                       *       ASB11315
C *****************************************************************       ASB11316
      SUBROUTINE DRAGX(WVELNX,WPVNX,SPD,SPW,                              ASB11317
     1PSPLAW,DEPWP,REWX,REWPX,CWDX,CWPDX)                                 ASB11318
C                                                                         ASB11319
C IF THE SPAR HAS AN ELLIPTICAL CROSS-SECTION, THEN                       ASB11320
C SUBROUTINE DRAGX CALCULATES REYNOLD'S NUMBERS AND DRAG                  ASB11321
C COEFFICIENTS FOR THE WIND AND WATER PARTICLE FORCES ACTING              ASB11322
C ON THE SPAR IN THE X DIRECTION.                                         ASB11323
C                                                                         ASB11324
      DIMENSION WVELNX(100),WPVNX(500),DEPWP(500)                         ASB11325
      DIMENSION REWX(100),REWPX(500),CWDX(100),CWPDX(500)                 ASB11326
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY              ASB11327
      COMMON NWDP,NCDP,NWADP,NWPDP                                        ASB11328
      IF(NWDP.EQ.0) GOTO 290                                              ASB11329
      DO 100 I=1,NWDP                                                     ASB11330
      REWX(I)=RAIR*ABS(WVELNX(I))*SPD/UAIR                                ASB11331
C                                                                         ASB11332
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C CALCULATE WIND REYNOLDS NUMBER                                        ASB11333
      IF(REWX(I).LT.10.00) GOTO 220                                     ASB11334
      IF(REWX(I).LE.6.5E05) GOTO 230                                    ASB11335
C                                                                       ASB11336
C CALCULATE THE TURBULENT COEFFICIENT OF WIND FRICTION                  ASB11337
      DO 200 JJ=1,1000000                                               ASB11338
      CF=FLOAT(JJ)/10000.                                               ASB11339
      A=.242/SQRT(CF)                                                   ASB11340
      B=ALOG10(CF*REWX(I))                                              ASB11341
      IF(B.GE.A) GOTO 210                                               ASB11342
  200 CONTINUE                                                          ASB11343
      WRITE(6,250) I,REWX(I),CF                                         ASB11344
  250 FORMAT(' ',/,/,/,/,/,/,43X,                                       ASB11345
     1'ERROR IN SUBROUTINE DRAGX - CHECK CALCULATIONS',/,/              ASB11346
     2'I = ',I2,10X,                                                    ASB11347
     3'REYNOLDS NUMBER = ',E13.3,10X,                                   ASB11348
     4'SKIN FRICTION COEFFICIENT = ',E13.3)                             ASB11349
      STOP                                                              ASB11350
C                                                                       ASB11351
C CALCULATE THE TURBULENT WIND DRAG COEFFICIENT                         ASB11352
  210 CWDX(I)=CF*4.+2.*(SPW/SPD)+120.*((SPD/SPW)**2)                    ASB11353
      GOTO 100                                                          ASB11354
C                                                                       ASB11355
C CHECK FOR ZERO REYNOLDS NUMBER                                        ASB11356
  220 CWDX(I)=0.00                                                      ASB11357
      GOTO 100                                                          ASB11358
C                                                                       ASB11359
C CALCULATE THE LAMINAR WIND DRAG COEFFICIENT                           ASB11360
  230 CF=0.0075                                                         ASB11361
      CWDX(I)=2.*CF*(1.+SPW/SPD)+1.1*(SPD/SPW)                          ASB11362
  100 CONTINUE                                                          ASB11363
  290 IF(NWPDP.EQ.0) GOTO 500                                           ASB11364
      DO 300 J=1,NWPDP                                                  ASB11365
      DEPWP(J)=DEPTH/FLOAT(NWPDP)*FLOAT(J)-DEPTH/(2.*FLOAT(NWPDP))      ASB11366
C                                                                       ASB11367
C CALCULATE WATER PARTICLE REYNOLDS NUMBER                              ASB11368
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      REWPX(J)=RWAT*ABS(WPVNX(J))*SPD/UWAT                              ASB11369
      IF(REWPX(J).LT.10.00) GOTO 420                                    ASB11370
      IF(REWPX(J).LE.6.5E05) GOTO 430                                   ASB11371
C                                                                       ASB11372
C CALCULATE THE TURBULENT COEFFICIENT OF WATER PARTICLE FRICTION         ASB11373
      DO 400 JJJ=1,1000000                                              ASB11374
      CF=FLOAT(JJJ)/10000.                                              ASB11375
      A=.242/SQRT(CF)                                                   ASB11376
      B=ALOG10(CF*REWPX(J))                                             ASB11377
      IF(B.GE.A) GOTO 410                                               ASB11378
  400 CONTINUE                                                          ASB11379
      WRITE(6,250) J,REWPX(J),CF                                        ASB11380
      STOP                                                              ASB11381
C                                                                       ASB11382
C CALCULATE THE TURBULENT WATER PARTICLE DRAG COEFFICIENT               ASB11383
  410 CWPDX(J)=CF*4.+2.*(SPW/SPD)+120.*((SPD/SPW)**2)                   ASB11384
      GOTO 300                                                          ASB11385
C                                                                       ASB11386
C CHECK FOR ZERO REYNOLDS NUMBER                                        ASB11387
  420 CWPDX(J)=0.00                                                     ASB11388
      GOTO 300                                                          ASB11389
C                                                                       ASB11390
C CALCULATE THE LAMINAR WATER PARTICLE DRAG COEFFICIENT                 ASB11391
  430 CF=0.0075                                                         ASB11392
      CWPDX(J)=2.*CF*(1.+SPW/SPD)+1.1*(SPD/SPW)                         ASB11393
  300 CONTINUE                                                          ASB11394
  500 RETURN                                                            ASB11395
      END                                                               ASB11396
C ***************************************************************       ASB11397
C *                        SUBROUTINE DRAGY                         *   ASB11398
C ***************************************************************       ASB11399
      SUBROUTINE DRAGY(WVELNY,WPVNY,SPD,SPW,PSPLAW,                     ASB11400
     1REWY,REWPY,CWDY,CWPDY)                                            ASB11401
C                                                                       ASB11402
C IF THE SPAR HAS AN ELLIPTICAL CROSS-SECTION, THEN                     ASB11403
C SUBROUTINE DRAGY CALCULATES REYNOLD'S NUMBERS AND DRAG                ASB11404
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C COEFFICIENTS FOR THE WIND AND WATER PARTICLE FORCES                    ASB11405
C ACTING ON THE SPAR IN THE Y DIRECTION.                                ASB11406
C                                                                       ASB11407
      DIMENSION WVELNY(100),WPVNY(500)                                  ASB11408
      DIMENSION REWY(100),REWPY(500),CWDY(100),CWPDY(500)               ASB11409
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB11410
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB11411
C                                                                       ASB11412
C CALCULATE WIND REYNOLDS NUMBER                                        ASB11413
      IF(NWDP.EQ.0) GOTO 290                                            ASB11414
      DO 100 I=1,NWDP                                                   ASB11415
      REWY(I)=RAIR*ABS(WVELNY(I))*SPW/UAIR                              ASB11416
      IF(REWY(I).LT.10.00) GOTO 210                                     ASB11417
C                                                                       ASB11418
C CALCULATE THE  WIND DRAG COEFFICIENT                                  ASB11419
      CWDY(I)=2.00                                                      ASB11420
      GOTO 100                                                          ASB11421
C                                                                       ASB11422
C CHECK FOR ZERO REYNOLDS NUMBER                                        ASB11423
  210 CWDY(I)=0.00                                                      ASB11424
      GOTO 100                                                          ASB11425
  100 CONTINUE                                                          ASB11426
C                                                                       ASB11427
C CALCULATE WATER PARTICLE REYNOLDS NUMBERS                             ASB11428
  290 IF(NWPDP.EQ.0) GOTO 500                                           ASB11429
      DO 300 J=1,NWPDP                                                  ASB11430
      REWPY(J)=RWAT*ABS(WPVNY(J))*SPW/UWAT                              ASB11431
      IF(REWPY(J).LT.10.00) GOTO 410                                    ASB11432
C                                                                       ASB11433
C CALCULATE THE TURBULENT WATER PARTICLE DRAG COEFFICIENT               ASB11434
      CWPDY(J)=2.00                                                     ASB11435
      GOTO 300                                                          ASB11436
C                                                                       ASB11437
C CHECK FOR ZERO REYNOLDS NUMBER                                        ASB11438
  410 CWPDY(J)=0.00                                                     ASB11439
      GOTO 300                                                          ASB11440
```

```
  300 CONTINUE                                                          ASB11441
  500 RETURN                                                            ASB11442
      END                                                               ASB11443
C ***************************************************************     ASB11444
C *                  SUBROUTINE FORCE                             *     ASB11445
C ***************************************************************     ASB11446
      SUBROUTINE FORCE (N,NWHPTS,SPD,SPW,CAREA,EWAX,                    ASB11447
     1EWAY,EWPAX,EWPAY,WVELNX,WVELNY,WPVNX,WPVNY,WPANX,WPANY,           ASB11448
     2CWDX,CWDY,CWPDX,CWPDY,CMX,CMY,WFX,WFY,TWFX,TWFY,                  ASB11449
     3WPDFX,WPDFY,WPIFX,WPIFY,WPFX,WPFY,TWPDFX,TWPDFY,                  ASB11450
     4TWPIFX,TWPIFY,TWFFX,TWPFY,TFX,TFY,TSBF)                           ASB11451
C                                                                       ASB11452
C SUBROUTINE FORCE COMPUTES THE WIND AND WATER PARTICLE                 ASB11453
C FORCES ACTING ON EACH ELEMENTAL AREA OF THE SPAR. IF                  ASB11454
C WAVES ARE PRESENT, THEN BOTH DRAG AND INERTIA FORCES ARE              ASB11455
C COMPUTED FOR EACH ELEMENT. IN ADDITION, THIS SUBROUTINE               ASB11456
C SUMS ALL OF THE INDIVIDUAL FORCES TO DETERMINE THE TOTAL              ASB11457
C FORCE ACTING ON THE SPAR.                                             ASB11458
C                                                                       ASB11459
      DIMENSION WVELNX(100),WVELNY(100)                                 ASB11460
      DIMENSION WPVNX(500),WPVNY(500),WPANX(500),WPANY(500)             ASB11461
      DIMENSION CWDX(100),CWDY(100),CWPDX(500),CWPDY(500)               ASB11462
      DIMENSION WFX(100),WFY(100)                                       ASB11463
      DIMENSION WPDFX(500),WPDFY(500),WPIFX(500),WPIFY(500)             ASB11464
      DIMENSION WPFX(500),WPFY(500)                                     ASB11465
      DIMENSION TSBF(100)                                               ASB11466
C                                                                       ASB11467
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB11468
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB11469
      W=SPW/2.0                                                         ASB11470
      D=SPD/2.0                                                         ASB11471
C                                                                       ASB11472
C COMPUTE HYDRODYNAMIC MASS COEFFICIENTS                                ASB11473
C     CMX=1.0+W/D                                                       ASB11474
      CMX=1.5                                                           ASB11475
C     CMY=1.0+D/W                                                       ASB11476
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```
      CMY=1.5                                                          ASB11477
      TWFX=0.0                                                         ASB11478
      TWFY=0.0                                                         ASB11479
      IF(NWDP.EQ.0) GOTO 150                                           ASB11480
C                                                                      ASB11481
C CALCULATE WIND DRAG FORCES ON THE SPAR BUOY                          ASB11482
      DO 100 I=1,NWDP                                                  ASB11483
      WFX(I)=0.5*RAIR*EWAX*WVELNX(I)*ABS(WVELNX(I))*CWDX(I)            ASB11484
      TWFX=TWFX+WFX(I)                                                 ASB11485
      WFY(I)=0.5*RAIR*EWAY*WVELNY(I)*ABS(WVELNY(I))*CWDY(I)            ASB11486
  100 TWFY=TWFY+WFY(I)                                                 ASB11487
C                                                                      ASB11488
C CALCULATE WATER PARTICLE DRAG, INERTIA AND TOTAL FORCES              ASB11489
C ON THE SPAR BUOY                                                     ASB11490
  150 TWPDFX=0.0                                                       ASB11491
      TWPIFX=0.0                                                       ASB11492
      TWPDFY=0.0                                                       ASB11493
      TWPIFY=0.0                                                       ASB11494
      TWPFX=0.0                                                        ASB11495
      TWPFY=0.0                                                        ASB11496
      IF(NWPDP.EQ.0) GOTO 300                                          ASB11497
      DO 200 I=1,NWPDP                                                 ASB11498
      WPDFX(I)=0.5*RWAT*EWPAX*WPVNX(I)*ABS(WPVNX(I))*CWPDX(I)          ASB11499
      TWPDFX=TWPDFX+WPDFX(I)                                           ASB11500
      WPIFX(I)=RWAT*CAREA*WPANX(I)*CMX                                 ASB11501
      TWPIFX=TWPIFX+WPIFX(I)                                           ASB11502
      WPFX(I)=WPDFX(I)+WPIFX(I)                                        ASB11503
      TWPFX=TWPFX+WPFX(I)                                              ASB11504
      WPDFY(I)=0.5*RWAT*EWPAY*WPVNY(I)*ABS(WPVNY(I))*CWPDY(I)          ASB11505
      TWPDFY=TWPDFY+WPDFY(I)                                           ASB11506
      WPIFY(I)=RWAT*CAREA*WPANY(I)*CMY                                 ASB11507
      TWPIFY=TWPIFY+WPIFY(I)                                           ASB11508
      WPFY(I)=WPDFY(I)+WPIFY(I)                                        ASB11509
  200 TWPFY=TWPFY+WPFY(I)                                              ASB11510
      TFX=TWFX+TWPFX                                                   ASB11511
      TFY=TWFY+TWPFY                                                   ASB11512
```

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      TSBF(N)=SQRT(TFX**2+TFY**2)                                       ASB11513
  300 RETURN                                                            ASB11514
      END                                                               ASB11515
C *****************************************************************   ASB11516
C *                        SUBROUTINE OTMOM                       *   ASB11517
C *****************************************************************   ASB11518
      SUBROUTINE OTMOM (WPX,WFY,WPFX,WPFY,PSPLAW,WAMP,CAREA,SPL,        ASB11519
     1SWWD,VL,VHGT,VMWWD,IVSUB,VWWD,TBWGT,TSWGT,ANCHX,ANCHY,IEND,       ASB11520
     2WOTMX,WOTMY,WPOTMX,WPOTMY,OTMOMX,OTMOMY)                          ASB11521
C                                                                       ASB11522
C SUBROUTINE OTMOM                                                      ASB11523
C                                                                       ASB11524
      DIMENSION WFX(100),WFY(100),WPFX(500),WPFY(500)                   ASB11525
      DIMENSION WMA(100),WPMA(500)                                      ASB11526
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY            ASB11527
      COMMON NWDP,NCDP,NWADP,NWPDP                                      ASB11528
C                                                                       ASB11529
C COMPUTE WIND OVERTURNING MOMENTS                                      ASB11530
      WOTMX=0.0                                                         ASB11531
      WOTMY=0.0                                                         ASB11532
      IF(NWDP.EQ.0) GOTO 100                                            ASB11533
      DELTL=(PSPLAW/FLOAT(NWDP))/2.0                                    ASB11534
      DO 200 I=1,NWDP                                                   ASB11535
      WMA(I)=PSPLAW/FLOAT(NWDP)*FLOAT(I)-DELTL                          ASB11536
      WOTMX=WOTMX+WFX(I)*WMA(I)                                         ASB11537
  200 WOTMY=WOTMY+WFY(I)*WMA(I)                                         ASB11538
C                                                                       ASB11539
C COMPUTE WATER PARTICLE OVERTURNING MOMENT                             ASB11540
  100 WPOTMX=0.0                                                        ASB11541
      WPOTMY=0.0                                                        ASB11542
      IF(NWPDP.EQ.0) GOTO 300                                           ASB11543
      DELTL=(DEPTH/FLOAT(NWPDP))/2.0                                    ASB11544
      D  400 II=1,NWPDP                                                 ASB11545
      T=DELTL*2.0*FLOAT(II-1)                                           ASB11546
      WPMA(II)=DEPTH-T-DELTL                                            ASB11547
      WPOTMX=WPOTMX+WPFX(II)*WPMA(II)                                   ASB11548
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  400 WPOTMY=WPOTMY+WPFY(II)*WPMA(II)                                    ASB11549
C                                                                        ASB11550
C CALCULATE THE SUBMERGED SPAR LENGTH AND THE WEIGHT OF THE              ASB11551
C WATER DISPLACED BY THE SPAR                                            ASB11552
      SSPL=(DEPTH+WAMP)/(COS(AOLX*PI/180.)*COS(AOLY*PI/180.))            ASB11553
      IVSUB=0                                                            ASB11554
      VMAX=(VHGT+VL/2.)/(COS(AOLX*PI/180.)*COS(AOLY*PI/180.))            ASB11555
      IF(SSPL.GT.VMAX) IVSUB=1                                           ASB11556
      VWWD=VMWWD                                                         ASB11557
      IF(IVSUB.NE.1) VWWD=VWWD/VL*((DEPTH+WAMP -(VHGT-VL/2.))/           ASB11558
     1(COS(AOLX*PI/180.)*COS(AOLY*PI/180.))                              ASB11559
      SWWD=CAREA*SSPL*RWAT*G                                             ASB11560
      TBWGT=SWWD+VWWD                                                    ASB11561
C                                                                        ASB11562
C COMPUTE OVERTURNING MOMENT DUE TO OFF-CENTER                           ASB11563
C ANCHOR ATTACHMENT POINT                                                ASB11564
  300 AAARMX=ANCHX*COS(AOLX)                                             ASB11565
      AAARMY=ANCHY*COS(AOLY)                                             ASB11566
      AAOTMX=AAARMX*(TBWGT-TSWGT)                                        ASB11567
      AAOTMY=AAARMY*(TBWGT-TSWGT)                                        ASB11568
      IF(IEND.EQ.1) GOTO 500                                             ASB11569
      ECOTMX=0.0                                                         ASB11570
      ECOTMY=0.0                                                         ASB11571
      GOTO 600                                                           ASB11572
C                                                                        ASB11573
C COMPUTE OVERTURNING MOMENT DUE TO END CAP                              ASB11574
  500 ECOTMX=7.5*SPL*SIN(AOLX*PI/180.)                                   ASB11575
      ECOTMY=7.5*SPL*SIN(AOLY*PI/180.)                                   ASB11576
C                                                                        ASB11577
C SUM OVERTURNING MOMENTS TO COMPUTE TOTAL OVERTURNING MOMENT            ASB11578
  600 OTMOMX=WOTMX+WPOTMX+AAOTMX+ECOTMX                                  ASB11579
      OTMOMY=WOTMY+WPOTMY+AAOTMY+ECOTMY                                  ASB11580
      RETURN                                                             ASB11581
      END                                                                ASB11582
C ***************************************************************        ASB11583
C *                      SUBROUTINE RMOM                          *      ASB11584
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C ***************************************************************      ASB11585
      SUBROUTINE RMOM (SPL,SPW,VW,VL,VHGT,SWGT,VWGT,WAMP,SWWD,VWWD,      ASB11586
     1IVSUB,WMOMX,WMOMY,BMOMX,BMOMY,RMOMX,RMOMY)                         ASB11587
C                                                                        ASB11588
C SUBROUTINE RMOM CALCULATES THE RIGHTING MOMENT OF THE                  ASB11589
C SPAR USING ARCHIMEDES PRINCIPLE                                        ASB11590
C                                                                        ASB11591
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY             ASB11592
      COMMON NWDP,NCDP,NWADE,NWPDP                                       ASB11593
C                                                                        ASB11594
C CALCULATE WEIGHT MOMENT ARMS                                           ASB11595
      SARMX=SPL/2.0*SIN(AOLX*PI/180.)                                    ASB11596
      SARMY=SPL/2.0*SIN(AOLY*PI/180.)                                    ASB11597
      VARMX=VHGT*TAN(AOLX*PI/180.)+((VW/2+SPW/2)*COS(AOLX*PI/180))       ASB11598
      VARMY=VHGT*TAN(AOLY*PI/180.)                                       ASB11599
C                                                                        ASB11600
C CALCULATE THE WEIGHT MOMENTS                                           ASB11601
      WMOMX=SWGT*SARMX+VWGT*VARMX                                        ASB11602
      WMOMY=SWGT*SARMY+VWGT*VARMY                                        ASB11603
C                                                                        ASB11604
C CALCULATE THE BUOYANT MOMENT ARMS                                      ASB11605
      SBARMX=(DEPTH+WAMP)/2.0*TAN(AOLX*PI/180.)                          ASB11606
      SBARMY=(DEPTH+WAMP)/2.0*TAN(AOLY*PI/180.)                          ASB11607
      VBARMX=VARMX                                                       ASB11608
      VBARMY=VARMY                                                       ASB11609
      IF(IVSUB.EQ.1) GOTO 100                                            ASB11610
      VLSUB=(DEPTH+WAMP)-(VHGT-VL/2.)                                    ASB11611
      VBARMX=(DEPTH+WAMP-VLSUB/2.)*TAN(AOLX*PI/180.)                     ASB11612
      VBARMY=(DEPTH+WAMP-VLSUB/2.)*TAN(AOLY*PI/180.)                     ASB11613
C                                                                        ASB11614
C CALCULATE THE BUOYANT MOMENTS                                          ASB11615
  100 BSMOMX=SWWD*SBARMX                                                 ASB11616
      BSMOMY=SWWD*SBARMY                                                 ASB11617
      BVMOMX=VWWD*VBARMX                                                 ASB11618
      BVMOMY=VWWD*VBARMY                                                 ASB11619
      BMOMX=BSMOMX+BVMOMX                                                ASB11620
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      BMOMY=BSMOMY+BVMOMY                                                ASB11621
                                                                         ASB11622
C                                                                        ASB11623
C CALCULATE RIGHTING MOMENTS                                             ASB11624
      RMOMX=BMOMX-WMOMX                                                  ASB11625
      RMOMY=BMOMY-WMOMY                                                  ASB11626
      RETURN                                                             ASB11627
      END                                                                ASB11628
C ******************************************************************     ASB11629
C *                        SUBROUTINE INOUT1                       *     ASB11630
C ******************************************************************     ASB11631
      SUBROUTINE INOUT1(ELEV,WAA,WSP,WVELX,                              ASB11632
     1WVELY,WVELNX,WVELNY,DEPC,DEPWP,VEL,DIR,CAA,CVX,CVY,CVNX,CVNY,      ASB11633
     2DEP,WAMP,HWAVX,HWAVY,VWAVX,VWAVY,WAVNX,WAVNY,WPVNX,WPVNY,          ASB11634
     3SPW,SPD,REWX,REWY,REWPX,REWPY,CWDX,CWDY,CWPDX,CWPDY)               ASB11635
C                                                                        ASB11636
C WHEN THE INTERMEDIATE OUTPUT NUMBER (ION) HAS BEEN SET TO 1,           ASB11637
C THIS SUBROUTINE WRITES OUT ALL OF THE INTERMEDIATE VALUES              ASB11638
C CALCULATED BY THE VARIOUS SUBROUTINES IN THIS PROGRAM, USED            ASB11639
C TO DETERMINE THE TOTAL FORCE ON THE SPAR.                              ASB11640
C                                                                        ASB11641
      DIMENSION ELEV(100),WSP(100)                                       ASB11642
      DIMENSION WVELX(100),WVELY(100),WVELNX(100),WVELNY(100)            ASB11643
      DIMENSION VEL(500),DIR(500),CAA(500)                               ASB11644
      DIMENSION DEP(500),DEPC(500),DEPWP(500)                            ASB11645
      DIMENSION CVX(500),CVY(500),CVNX(500),CVNY(500)                    ASB11646
      DIMENSION WPVNX(500),WPVNY(500)                                    ASB11647
      DIMENSION HWAVX(500),HWAVY(500),VWAVX(500),VWAVY(500)              ASB11648
      DIMENSION WAVNX(500),WAVNY(500),WAVTX(500),WAVTY(500)              ASB11649
      DIMENSION XREL(500),YREL(500),AX(500),AY(500),BX(500),BY(500)      ASB11650
      DIMENSION WAANX(500),WAANY(500)                                    ASB11651
      DIMENSION REWX(100),REWY(100),REWPX(500),REWPY(500)                ASB11652
      DIMENSION CWDX(100),CWDY(100),CWPDX(500),CWPDY(500)                ASB11653
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY             ASB11654
      COMMON NWDP,NCDP,NWADP,NWPDP                                       ASB11655
      DATA SXD/'X - '/,SYD/'Y - '/                                       ASB11656
C
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      IF(NWDP.EQ.0) GOTO 200                                          ASB11657
      WRITE(6,105)                                                    ASB11658
  105 FORMAT('1',53X,'WIND VELOCITY INFORMATION',/,/,59X,             ASB11659
     1'X - DIRECTION',/,/,/,10X,'ELEVATION',10X,                      ASB11660
     2'WIND ANGLE',9X,'WIND SPEED',9X,'WIND VELOCITY',9X,             ASB11661
     3'LIST ANGLE',10X,'WIND VELOCITY',/,29X,'OF ATTACK',68X,         ASB11662
     4'NORMAL TO THE BUOY',/,11X,'(FEET)',12X,'(DEGREES)',10X,        ASB11663
     6'(FT./SEC.)',12X,'(FT.SEC.)',11X,'(DEGREES)',11X,               ASB11664
     7'(FT./SEC.)')                                                   ASB11665
      DO 110 I=1,NWDP                                                 ASB11666
  110 WRITE(6,115) ELEV(I),WAA,WSP(I),WVELX(I),AOLX,WVELNX(I)         ASB11667
  115 FORMAT('0',11X,F5.2,14X,F5.1,12X,F7.2,14X,F7.3,14X,F7.2,        ASB11668
     111X,F7.2)                                                       ASB11669
      WRITE(6,125)                                                    ASB11670
  125 FORMAT('1',53X,'WIND VELOCITY INFORMATION',/,/,59X,             ASB11671
     1'Y - DIRECTION',/,/,/,10X,'ELEVATION',10X,                      ASB11672
     2'WIND ANGLE',9X,'WIND SPEED',9X,'WIND VELOCITY',9X,             ASB11673
     3'LIST ANGLE',10X,'WIND VELOCITY',/,29X,'OF ATTACK',68X,         ASB11674
     4'NORMAL TO THE BUOY',/,11X,'(FEET)',12X,'(DEGREES)',10X,        ASB11675
     5'(FT./SEC.)',12X,'(FT.SEC.)',11X,'(DEGREES)',11X,               ASB11676
     6'(FT./SEC.)')                                                   ASB11677
      DO 130 I=1,NWDP                                                 ASB11678
  130 WRITE(6,115) ELEV(I),WAA,WSP(I),WVELY(I),AOLY,WVELNY(I)         ASB11679
  200 IF(NCDP.EQ.0) GOTO 300                                          ASB11680
      WRITE(6,205)                                                    ASB11681
  205 FORMAT('1',51X,'CURRENT VELOCITY INFORMATION',/,/,7X,           ASB11682
     1'DEPTH',9X,'CURRENT SPEED',9X,'CURRENT',9X,                     ASB11683
     2'CURRENT ANGLE',9X,'CURRENT VELOCITY',9X,                       ASB11684
     3'CURRENT VELOCITY',/,42X,'DIRECTION',9X,                        ASB11685
     4'OF ATTACK',12X,'X - DIRECTION',12X,                            ASB11686
     5'Y - DIRECTION',/,6X,'(FEET)',10X,                              ASB11687
     6'(FT./SEC.)',10X,'(DEGREES)',10X,'(DEGREES)',14X,               ASB11688
     7'(FT./SEC.)',14X,'(FT./SEC.)')                                  ASB11689
      DO 210 I=1,NCDP                                                 ASB11690
  210 WRITE(6,215) DEPC(I),VEL(I),DIR(I),CAA(I),CVX(I),CVY(I)         ASB11691
  215 FORMAT('0',5X,F6.2,13X,F5.2,14X,F5.1,13X,F6.1,18X,F6.2,         ASB11692
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     117X,F6.2)                                                                  ASB11693
      WRITE(6,225)                                                               ASB11694
  225 FORMAT('1',45X,'CURRENT VELOCITY INFORMATION (CONTINUED)',/,/,35X,         ASB11695
     1'X - DIRECTION',45X,'Y - DIRECTION',/,/,5X,                                ASB11696
     2'DEPTH',5X,'CURRENT VELOCITY',5X,'LIST ANGLE',6X,                          ASB11697
     3'CURRENT VELOCITY',6X,'CURRENT VELOCITY',5X,                               ASB11698
     4'LIST ANGLE',6X,'CURRENT VELOCITY',/,51X,                                  ASB11699
     5'NORMAL TO THE BUOY',41X,'NORMAL TO THE BUOY',/,4X,                        ASB11700
     6'(FEET)',8X,'(FT./SEC.)',8X,'(DEGREES)',10X,                              ASB11701
     7'(FT./SEC.)',12X,'(FT./SEC.)',8X,'(DEGREES)',10X,                         ASB11702
     8'(FT./SEC.)')                                                             ASB11703
      DO 230 I=1,NCDP                                                           ASB11704
  230 WRITE(6,235) DEPC(I),CVX(I),AOLX,CVNX(I),CVY(I),AOLY,CVNY(I)              ASB11705
  235 FORMAT('0',4X,F6.2,2(10X,F6.2),13X,F6.2,15X,F6.2,13X,F6.2,                ASB11706
     113X,F6.2)                                                                 ASB11707
  300 IF(NWADP.EQ.0) GOTO 400                                                   ASB11708
      WRITE(6,310)  SXD,WAMP,AOLX,ICOUNT                                        ASB11709
  310 FORMAT('1',49X,                                                           ASB11710
     1'WAVE PARTICLE VELOCITY INFORMATION',/,/,59X,                             ASB11711
     2A4,'DIRECTION',/,/,/,40X,                                                 ASB11712
     3'WAVE AMPLITUDE = ',23X,F6.3,' FEET',/,/,40X,                             ASB11713
     4'LIST ANGLE = ',27X,F7.3,' DEGREES',/,/,/,60X,                            ASB11714
     5'ICOUNT = ',I3,/,/,9X,                                                    ASB11715
     6'ABSOLUTE',9X,'HORIZONTAL PARTICLE',9X,                                   ASB11716
     7'VERTICAL PARTICLE',9X,'RELATIVE PARTICLE',9X,                            ASB11717
     8'RELATIVE PARTICLE',/,10X,'DEPTH',16X,                                    ASB11718
     9'VELOCITY',19X,'VELOCITY',18X,'VELOCITY',18X,                             ASB11719
     X'DIRECTION',/,10X,'(FEET)',14X,                                           ASB11720
     1'(FT./SEC.)',17X,'(FT./SEC.)',16X,'(FT./SEC.)',17X,                       ASB11721
     2'(DEGREES)')                                                              ASB11722
      DO 320 I=1,NWADP                                                          ASB11723
  320 WRITE(6,330) DEP(I),HWAVX(I),VWAVX(I),XREL(I),BX(I)                       ASB11724
  330 FORMAT('0',9X,F6.3,15X,F7.3,20X,F7.3,19X,F7.3,20X,F7.3)                   ASB11725
      WRITE(6,340) SXD,WAMP,AOLX,ICOUNT                                         ASB11726
  340 FORMAT('1',43X,                                                           ASB11727
     1'WAVE PARTICLE VELOCITY INFORMATION (CONTINUED)',/,/,59X,                 ASB11728
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     2A4,'DIRECTION',/,/,/,40X,                                          ASB11729
     3'WAVE AMPLITUDE = ',23X,F6.3,' FEET',/,/,40X,                      ASB11730
     4'LIST ANGLE = ',27X,F6.3,' DEGREES',/,/,/,60X,                     ASB11731
     5'ICOUNT = ',I3,/,/,14X,                                            ASB11732
     6'ABSOLUTE',13X,                                                    ASB11733
     7'RELATIVE PARTICLE',14X,'PARTICLE VELOCITY',15X,                   ASB11734
     8'PARTICLE VELOCITY',/,15X,'DEPTH',16X,                             ASB11735
     9'ANGLE OF ATTACK',14X,'NORMAL TO THE BUOY',13X,                    ASB11736
     X'TANGENTIAL TO THE BUOY',/,15X,'(FEET)',18X,                       ASB11737
     1'(DEGREES)',22X,'(FT./SEC.)',22X,                                  ASB11738
     2'(FT./SEC.)')                                                      ASB11739
      DO 350 I=1,NWADP                                                   ASB11740
350  WRITE(6,355) DEP(I),AX(I),WAVNX(I),WAVTX(I)                         ASB11741
355  FORMAT('0',14X,F6.3,18X,F7.3,23X,F9.3,23X,F9.3)                     ASB11742
     WRITE(6,310)  SYD,WAMP,AOLY,ICOUNT                                  ASB11743
     DO 370 I=1,NWADP                                                    ASB11744
370  WRITE(6,330) DEP(I),HWAVY(I),VWAVY(I),YREL(I),BY(I)                 ASB11745
     WRITE(6,340) SYD,WAMP,AOLY,ICOUNT                                   ASB11746
     DO 395 I=1,NWADP                                                    ASB11747
395  WRITE(6,355) DEP(I),AY(I),WAVNY(I),WAVTY(I)                         ASB11748
400  IF(SPW.NE.SPD) GOTO 600                                             ASB11749
     IF(NWDP.EQ.0) GOTO 500                                              ASB11750
     WRITE(6,410) RAIR,UAIR                                              ASB11751
410  FORMAT('1',49X,'WIND DRAG COEFFICIENT INFORMATION',/,/,59X,         ASB11752
    1'X - DIRECTION',/,/,17X,                                            ASB11753
    2'AIR DENSITY = ',F7.5,' SLUGS/FT. ** 3',17X,                        ASB11754
    3'AIR VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,13X,              ASB11755
    4'ELEVATION',16X,'WIND',16X,'CHARACTERISTIC',14X,                    ASB11756
    5'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                         ASB11757
    6'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                    ASB11758
    7'(FEET)',15X,'(FT./SEC.)',17X,'(FEET)')                            ASB11759
     DO 420 I=1,NWDP                                                     ASB11760
420  WRITE(6,430) ELEV(I),WVELNX(I),SPD,REWX(I),CWDX(I)                  ASB11761
430  FORMAT('0',13X,F5.2,18X,F6.3,20X,F5.3,17X,E12.6,15X,F5.3)           ASB11762
     WRITE(6,460) RAIR,UAIR                                              ASB11763
460  FORMAT('1',49X,'WIND DRAG COEFFICIENT INFORMATION',/,/,59X,         ASB11764
```

```
     1'Y - DIRECTION',/,/,17X,                                          ASB11765
     2'AIR DENSITY = ',F7.5,' SLUGS/FT. ** 3',17X,                      ASB11766
     3'AIR VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,13X,            ASB11767
     4'ELEVATION',16X,'WIND',16X,'CHARACTERISTIC',14X,                  ASB11768
     5'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                       ASB11769
     6'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                  ASB11770
     7'(FEET)',15X,'(FT./SEC.)',19X,'(FEET)')                           ASB11771
      DO 470 I=1,NWDP                                                   ASB11772
470  WRITE(6,430) ELEV(I),WVELNX(I),SPD,REWY(I),CWDY(I)                 ASB11773
500  IF(NWPDP.EQ.0) GOTO 800                                           ASB11774
     WRITE(6,510) RWAT,UWAT                                            ASB11775
510  FORMAT('1',44X,                                                   ASB11776
     1'WATER PARTICLE DRAG COEFFICIENT INFORMATION',/,/,59X,            ASB11777
     2'X - DIRECTION',/,/,16X,                                         ASB11778
     3'WATER DENSITY = ',F7.5,' SLUGS/FT. ** 3',15X,                   ASB11779
     4'WATER VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,15X,         ASB11780
     5'DEPTH',13X,'WATER PARTICLE',11X,'CHARACTERISTIC',14X,            ASB11781
     6'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                      ASB11782
     7'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                 ASB11783
     8'(FEET)',15X,'(FT./SEC.)',17X,'(FEET)')                          ASB11784
      DO 520 I=1,NWPDP                                                  ASB11785
520  WRITE(6,530) DEPWP(I),WPVNX(I),SPD,REWPX(I),CWPDX(I)              ASB11786
530  FORMAT('0',13X,F6.2,17X,F6.3,20X,F5.3,16X,E12.6,15X,F5.3)         ASB11787
     WRITE(6,560) RWAT,UWAT                                            ASB11788
560  FORMAT('1',44X,                                                   ASB11789
     1'WATER PARTICLE DRAG COEFFICIENT INFORMATION',/,/,59X,            ASB11790
     2'Y - DIRECTION',/,/,16X,                                         ASB11791
     3'WATER DENSITY = ',F7.5,' SLUGS/FT. ** 3',15X,                   ASB11792
     4'WATER VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,15X,         ASB11793
     5'DEPTH',13X,'WATER PARTICLE',11X,'CHARACTERISTIC',14X,            ASB11794
     6'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                      ASB11795
     7'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                 ASB11796
     8'(FEET)',15X,'(FT./SEC.)',17X,'(FEET)')                          ASB11797
      DO 570 I=1,NWPDP                                                  ASB11798
570  WRITE(6,530) DEPWP(I),WPVNY(I),SPD,REWPY(I),CWPDY(I)              ASB11799
     GOTO 800                                                          ASB11800
```

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600 IF(NWDP.EQ.0) GOTO 700                                                    ASB11801
    WRITE(6,610) RAIR,UAIR                                                    ASB11802
610 FORMAT('1',49X,'WIND DRAG COEFFICIENT INFORMATION',/,/,59X,               ASB11803
   1'X - DIRECTION',/,/,17X,                                                  ASB11804
   2'AIR DENSITY = ',F7.5,' SLUGS/FT. ** 3',17X,                              ASB11805
   3'AIR VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,13X,                    ASB11806
   4'ELEVATION',16X,'WIND',16X,'CHARACTERISTIC',14X,                          ASB11807
   5'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                               ASB11808
   6'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                          ASB11809
   7'(FEET)',15 X,'(FT./SEC.)',17X,'(FEET)')                                  ASB11810
    DO 620 I=1,NWDP                                                           ASB11811
620 WRITE(6,630) ELEV(I),WVELNX(I),SPD,REWX(I),CWDX(I)                        ASB11812
630 FORMAT('0',13X,F5.2,18X,F6.3,20X,F5.3,17X,E12.6,15X,F5.3)                 ASB11813
    WRITE(6,660) RAIR,UAIR                                                    ASB11814
660 FORMAT('1',49X,'WIND DRAG COEFFICIENT INFORMATION',/,/,59X,               ASB11815
   1'Y - DIRECTION',/,/,17X,                                                  ASB11816
   2'AIR DENSITY = ',F7.5,' SLUGS/FT. ** 3',17X,                              ASB11817
   3'AIR VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,13X,                    ASB11818
   4'ELEVATION',16X,'WIND',16X,'CHARACTERISTIC',14X,                          ASB11819
   5'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                               ASB11820
   6'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                          ASB11821
   7'(FEET)',15X,'(FT./SEC.)',19X,'(FEET)')                                   ASB11822
    DO 670 I=1,NWDP                                                           ASB11823
670 WRITE(6,630) ELEV(I),WVELNY(I),SPW,REWY(I),CWDY(I)                        ASB11824
700 IF(NWPDP.EQ.0) GOTO 800                                                   ASB11825
    WRITE(6,710) RWAT,UWAT                                                    ASB11826
710 FORMAT('1',44X,                                                           ASB11827
   1'WATER PARTICLE DRAG COEFFICIENT INFORMATION',/,/,59X,                    ASB11828
   2'X - DIRECTION',/,/,16X,                                                  ASB11829
   3'WATER DENSITY = ',F7.5,' SLUGS/FT. ** 3',15X,                            ASB11830
   4'WATER VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,15X,                  ASB11831
   X'DEPTH',13X,'WATER PARTICLE',11X,'CHARACTERISTIC',14X,                    ASB11832
   5'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                               ASB11833
   6'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                          ASB11834
   7'(FEET)',15X,'(FT./SEC.)',17X,'(FEET)')                                   ASB11835
    DO 720 I=1,NWPDP                                                          ASB11836
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  720 WRITE(6,730) DEPWP(I),WPVNX(I),SPD,REWPX(I),CWPDX(I)                  ASB11837
  730 FORMAT('0',13X,F6.2,17X,F6.3,20X,F5.3,16X,E12.6,15X,F5.3)             ASB11838
      WRITE(6,760) RWAT,UWAT                                                ASB11839
  760 FORMAT('1',44X,                                                       ASB11840
     1'WATER PARTICLE DRAG COEFFICIENT INFORMATION',/,/,59X,                ASB11841
     2'Y - DIRECTION',/,/,16X,                                              ASB11842
     3'WATER DENSITY = ',F7.5,' SLUGS/FT. ** 3',15X,                        ASB11843
     4'WATER VISCOSITY = ',F12.10,' SLUGS/FT. * SEC.',/,/,15X,              ASB11844
     5'DEPTH',13X,'WATER PARTICLE',11X,'CHARACTERISTIC',14X,                ASB11845
     6'REYNOLDS',17X,'DRAG',/,36X,'VELOCITY',17X,                          ASB11846
     7'DIAMETER',18X,'NUMBER',15X,'COEFFICIENT',/,14X,                     ASB11847
     8'(FEET)',15X,'(FT./SEC.)',17X,'(FEET)')                              ASB11848
      DO 770 I=1,NWPDP                                                      ASB11849
  770 WRITE(6,730) DEPWP(I),WPVNY(I),SPW,REWPY(I),CWPDY(I)                  ASB11850
  800 RETURN                                                                ASB11851
      END                                                                   ASB11852
C *************************************************************           ASB11853
C *                      SUBROUTINE INOUT2                    *           ASB11854
C *************************************************************           ASB11855
      SUBROUTINE INOUT2(EWAX,EWAY,CAREA,CMX,CMY,ELEV,                       ASB11856
     1WFX,WFY,TWFX,TWFY,EWPAX,EWPAY,DEPWP,WPDFX,WPDFY,WPIFX,WPIFY,          ASB11857
     2WPFX,WPFY,TWPDFX,TWPDFY,TWPIFX,TWPIFY,TWPFX,TWPFY,WOTMX,              ASB11858
     3WOTMY,WPOTMX,WPOTMY,OTMOMX,OTMOMY,IART,WMOMX,WMOMY,                   ASB11859
     4BMOMX,BMOMY,RMOMX,RMOMY)                                              ASB11860
C                                                                           ASB11861
C WHEN THE INTERMEDIATE OUTPUT NUMBER (ION) HAS BEEN SET EQUAL TO 1,        ASB11862
C THIS SUBROUTINE WRITES OUT THE WIND AND WATER PARTICLE FORCES ON          ASB11863
C EACH ELEMENTAL AREA AS WELL AS THE TOTAL FORCE ON THE SPAR. IN            ASB11864
C ADDITION, ALL OVERTURNING AND RIGHTING MOMENTS IN BOTH THE X AND          ASB11865
C Y DIRECTIONS ARE WRITTEN OUT.                                             ASB11866
C                                                                           ASB11867
      DIMENSION ELEV(100)                                                   ASB11868
      DIMENSION WFX(100),WFY(100)                                           ASB11869
      DIMENSION DEPWP(500)                                                  ASB11870
      DIMENSION WPDFX(500),WPDFY(500),WPIFX(500),WPIFY(500)                 ASB11871
      DIMENSION WPFX(500),WPFY(500)                                         ASB11872
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      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,.OLY                ASB11873
      COMMON NWDP,NCDP,NWADP,NWPDP                                          ASB11874
C                                                                           ASB11875
      IF(NWDP.EQ.0) GOTO 900                                                ASB11876
      WRITE(6,810) RAIR,EWAX,CAREA,CMX                                      ASB11877
  810 FORMAT('1',55X,'WIND FORCE INFORMATION',/,/,59X,                      ASB11878
     1'X - DIRECTION',/,/,/,40X,                                            ASB11879
     2'MASS DENSITY OF AIR = ',19X,F6.4,' SLUGS/FT * 3',/,/,40X,            ASB11880
     3'ELEMENTAL AREA = ',23X,F6.3,' FEET ** 2',/,/,40X,                    ASB11881
     4'CROSS-SECTIONAL AREA = ',17X,F6.3,' FEET **  2',/,/,40X,             ASB11882
     5'HYDRODYNAMIC MASS COEFFICIENT = ',9X,F4.2,/,/,/,39X,                 ASB11883
     6'AVERAGE',37X,'TOTAL WIND',/,38X,                                     ASB11884
     7'ELEVATION',38X,'FORCE',/,40X,'(FEET)',38X,'(POUNDS)')                ASB11885
      DO 820 I=1,NWDP                                                       ASB11886
  820 WRITE(6,830) ELEV(I),WFX(I)                                           ASB11887
  830 FORMAT('0',36X,F6.2,27X,F12.2)                                        ASB11888
      WRITE(6,840) TWFX                                                     ASB11889
  840 FORMAT('0',43X,'TOTAL = ',F12.2)                                      ASB11890
      WRITE(6,860) RAIR,EWAY,CAREA,CMY                                      ASB11891
  860 FORMAT('1',55X,'WIND FORCE INFORMATION',/,/,59X,                      ASB11892
     1'Y - DIRECTION',/,/,/,40X,                                            ASB11893
     2'MASS DENSITY OF AIR = ',19X,F6.4,' SLUGS/FT * 3',/,/,40X,            ASB11894
     3'ELEMENTAL AREA = ',23X,F6.3,' FEET ** 2',/,/,40X,                    ASB11895
     4'CROSS-SECTIONAL AREA = ',17X,F6.3,' FEET **  2',/,/,40X,             ASB11896
     5'HYDRODYNAMIC MASS COEFFICIENT = ',9X,F4.2,/,/,/,39X,                 ASB11897
     6'AVERAGE',37X,'TOTAL WIND',/,38X,                                     ASB11898
     7'ELEVATION',40X,'FORCE',/,40X,'(FEET)',38X,'(POUNDS)')                ASB11899
      DO 870 I=1,NWDP                                                       ASB11900
  870 WRITE(6,830) ELEV(I),WFY(I)                                           ASB11901
      WRITE(6,840) TWFY                                                     ASB11902
  900 IF(NWPDP.EQ.0) GOTO 1000                                              ASB11903
      WRITE(6,910) RWAT,EWPAX,CAREA,CMX                                     ASB11904
  910 FORMAT('1',50X,'WATER PARTICLE FORCE INFORMATION',/,/,59X,            ASB11905
     1'X - DIRECTION',/,/,/,40X,                                            ASB11906
     2'MASS DENSITY OF WATER = ',17X,F6.4,' SLUGS/FT * 3',/,/,40X,          ASB11907
     3'ELEMENTAL AREA = ',23X,F6.3,' FEET ** 2',/,/,40X,                    ASB11908
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     4'CROSS-SECTIONAL AREA = ',17X,F6.3,' FEET **  2',/./,40X,                ASB11909
     5'HYDRODYNAMIC MASS COEFFICIENT = ',9X,F4.2,/,/,/,20X,                    ASB11910
     6'AVERAGE',21X,'DRAG',22X,'INERTIA',21X,'TOTAL WAVE',/,21X,               ASB11911
     7'DEPTH',21X,'FORCE',23X,'FORCE',20X,'PARTICLE FORCE',/,20X,              ASB11912
     8'(FEET)',20X,'(POUNDS)',20X,'(POUNDS)',21X,'(POUNDS)')                  ASB11913
      DO 920 I=1,NWPDP                                                         ASB11914
  920 WRITE(6,930) DEPWP(I),WPDFX(I),WPIFX(I),WPFX(I)                          ASB11915
  930 FORMAT('0',19X,F6.2,16X,F12.2,16X,F12.2,18X,F12.2)                       ASB11916
      WRITE(6,940) TWPDFX,TWPIFX,TWPFX                                         ASB11917
  940 FORMAT('0',33X,'TOTAL = ',F12.2,8X,'TOTAL = ',F12.2,11X,                 ASB11918
     1'TOTAL = ',F12.2)                                                        ASB11919
      WRITE(6,960) RWAT,EWPAY,CAREA,CMY                                        ASB11920
  960 FORMAT('1',50X,'WATER PARTICLE FORCE INFORMATION',/,/,59X,               ASB11921
     1'Y - DIRECTION',/,/,/,40X,                                               ASB11922
     2'MASS DENSITY OF WATER = ',17X,F6.4,' SLUGS/FT * 3',/,/,40X,             ASB11923
     3'ELEMENTAL AREA = ',23X,F6.3,' FEET ** 2',/,/,40X,                       ASB11924
     4'CROSS-SECTIONAL AREA = ',17X,F6.3,' FEET **  2',/,/,40X,                ASB11925
     5'HYDRODYNAMIC MASS COEFFICIENT = ',9X,F4.2,/,/,/,20X,                    ASB11926
     6'AVERAGE',21X,'DRAG',22X,'INERTIA',21X,'TOTAL WAVE',/,21X,               ASB11927
     7'DEPTH',21X,'FORCE',23X,'FORCE',20X,'PARTICLE FORCE',/,20X,              ASB11928
     8'(FEET)',20X,'(POUNDS)',20X,'(POUNDS)',21X,'(POUNDS)')                  ASB11929
      DO 970 I=1,NWPDP                                                         ASB11930
  970 WRITE(6,930) DEPWP(I),WPDFY(I),WPIFY(I),WPFY(I)                          ASB11931
      WRITE(6,940) TWPDFY,TWPIFY,TWPFY                                         ASB11932
 1000 CONTINUE                                                                 ASB11933
      WRITE(6,1010) WOTMX,WOTMY,WPOTMX,WPOTMY,OTMOMX,OTMOMY                    ASB11934
 1010 FORMAT('1',52X,'TABLE OF OVERTURNING MOMENTS',/,/,/,65X,                 ASB11935
     1'X-MOMENT',26X,'Y-MOMENT',/,/,25X,                                       ASB11936
     2'WIND MOMENT',26X,F10.2,24X,F10.2,/,/,25X,                               ASB11937
     3'WATER PARTICLE MOMENT',16X,F10.2,24X,F10.2,/,/,25X,                     ASB11938
     4'TOTAL MOMENT',25X,F10.2,24X,F10.2)                                      ASB11939
      IF(IART.NE.1) GOTO 1200                                                  ASB11940
      WRITE(6,1110) WMOMX,WMOMY,BMOMX,BMOMY,RMOMX,RMOMY                        ASB11941
 1110 FORMAT('1',54X,'TABLE OF RIGHTING MOMENTS',/,/,/,65X,                    ASB11942
     1'X-MOMENT',26X,'Y-MOMENT',/,/,25X,                                       ASB11943
     2'WEIGHT MOMENT',24X,F10.2,24X,F10.2,/,/,25X,                             ASB11944
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     3'BUOYANT MOMENT',23X,F10.2,24X,F10.2,/,/,25X,                    ASB11945
     4'TOTAL MOMENT',25X,F10.2,24X,F10.2)                              ASB11946
 1200 RETURN                                                           ASB11947
      END                                                              ASB11948
C ***************************************************************     ASB11949
C *                        SUBROUTINE ANCHOR                        *   ASB11950
C ***************************************************************     ASB11951
      SUBROUTINE ANCHOR(NWHPTS,TSWGT,SBWGT)                            ASB11952
C                                                                      ASB11953
C SUBROUTINE ANCHOR  DETERMINES THE RESERVE BUOYANCY OF THE            ASB11954
C SPAR AND THEN MATCHES THIS WITH A STANDARD COAST GUARD SINKER.       ASB11955
C NOTE THAT THE COAST GUARD SINKERS ARE SPECIFIED BY THEIR WEIGHT      ASB11956
C IN AIR BUT ARE MATCHED WITH THE RESERVE BUOYANCY OF THE SPAR BY      ASB11957
C THEIR WEIGHT IN WATER.                                               ASB11958
C                                                                      ASB11959
      DIMENSION SBWGT(100)                                             ASB11960
      COMMON PI,G,DEPTH,RAIR,RWAT,UAIR,UWAT,ICOUNT,AOLX,AOLY           ASB11961
      COMMON NWDP,NCDP,NWADP,NWPDP                                     ASB11962
C                                                                      ASB11963
C DEFINE MASS DENSITY OF CONCRETE                                      ASB11964
      RCON=4.476                                                       ASB11965
C                                                                      ASB11966
C CALCULATE WEIGHTS IN WATER OF STANDARD COAST GUARD SINKERS           ASB11967
      S1=20.*20.*8./1728.*(RCON-RWAT)*G                                ASB11968
      S2=24.*24.*10./1728.*(RCON-RWAT)*G                               ASB11969
      S3=32.*32.*12./1728.*(RCON-RWAT)*G                               ASB11970
      S4=40.*40.*15./1728.*(RCON-RWAT)*G                               ASB11971
      S5=45.*45.*18./1728.*(RCON-RWAT)*G                               ASB11972
      S6=50.*50.*19./1728.*(RCON-RWAT)*G                               ASB11973
      S7=54.*54.*21./1728.*(RCON-RWAT)*G                               ASB11974
      S8=58.*58.*23./1728.*(RCON-RWAT)*G                               ASB11975
      S9=60.*60.*28./1728.*(RCON-RWAT)*G                               ASB11976
      S10=60.*60.*42./1728.*(RCON-RWAT)*G                              ASB11977
C                                                                      ASB11978
C CALCULATE THE MAXIMUM TOTAL BUOYANT WEIGHT                           ASB11979
      TBWMAX=0.0                                                       ASB11980
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      DO 100 I=1,NWHPTS                                                  ASB11981
  100 TBWMAX=AMAX1(TBWMAX,SBWGT(I))                                      ASB11982
C                                                                        ASB11983
C CALCULATE THE RESERVE BUOYANCY OF THE SPAR                             ASB11984
      RB=TBWMAX-TSWGT                                                    ASB11985
C                                                                        ASB11986
C DETERMINE THE APPROPRIATE ANCHOR SIZE                                  ASB11987
      IF(RB.LT.S1) GOTO 200                                              ASB11988
      IF(RB.LT.S2) GOTO 300                                              ASB11989
      IF(RB.LT.S3) GOTO 400                                              ASB11990
      IF(RB.LT.S4) GOTO 500                                              ASB11991
      IF(RB.LT.S5) GOTO 600                                              ASB11992
      IF(RB.LT.S6) GOTO 700                                              ASB11993
      IF(RB.LT.S7) GOTO 800                                              ASB11994
      IF(RB.LT.S8) GOTO 900                                              ASB11995
      IF(RB.LT.S9) GOTO 1000                                             ASB11996
      IF(RB.LT.S10) GOTO 1100                                            ASB11997
C                                                                        ASB11998
C WRITE OUT APPROPRIATE ANCHOR SIZE                                      ASB11999
      WRITE(6,1205) RB                                                   ASB12000
 1205 FORMAT('1',44X,'MINIMUM REQUIRED ANCHOR SIZE IS ',F8.2,            ASB12001
     1' LBS.',/,/,/,/,18X,                                               ASB12002
     2'THIS BUOY DESIGN CANNOT BE SECURED TO T IE BOTTOM WITH JUST A SINGL ASB12003
     3E COAST GUARD SINKER')                                             ASB12004
      GOTO 1200                                                          ASB12005
  200 FS=S1/RB                                                           ASB12006
      WRITE(6,1215) RB,FS                                                ASB12007
 1215 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,         ASB12008
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                           ASB12009
     2' LBS',/,/,/,/,27X,'A 250 LB. STANDARD COAST GUARD ANCHOR WILL PROVI ASB12010
     3DE A FACTOR OF SAFTEY OF ',F4.1)                                   ASB12011
      GOTO 1200                                                          ASB12012
  300 FS=S2/RB                                                           ASB12013
      WRITE(6,1225) RB,FS                                                ASB12014
 1225 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,         ASB12015
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                           ASB12016
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     2' LBS',/,/,/,/,27X,'A 500 LB. STANDARD COAST GUARD ANCHOR WILL PROVI   ASB12017
     3DE A FACTOR OF SAFTEY OF ',F4.1)                                      ASB12018
      GOTO 1200                                                             ASB12019
  400 FS=S3/RB                                                              ASB12020
      WRITE(6,1235) RB,FS                                                   ASB12021
 1235 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,            ASB12022
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                              ASB12023
     2' LBS',/,/,/,/,27X,'A 1000 LB. STANDARD COAST GUARD ANCHOR WILL PROV  ASB12024
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                     ASB12025
      GOTO 1200                                                             ASB12026
  500 FS=S4/RB                                                              ASB12027
      WRITE(6,1245) RB,FS                                                   ASB12028
 1245 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,            ASB12029
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                              ASB12030
     2' LBS',/,/,/,/,27X,'A 2000 LB. STANDARD COAST GUARD ANCHOR WILL PROV  ASB12031
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                     ASB12032
      GOTO 1200                                                             ASB12033
  600 FS=S5/RB                                                              ASB12034
      WRITE(6,1255) RB,FS                                                   ASB12035
 1255 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,            ASB12036
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                              ASB12037
     2' LBS',/,/,/,/,27X,'A 3000 LB. STANDARD COAST GUARD ANCHOR WILL PROV  ASB12038
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                     ASB12039
      GOTO 1200                                                             ASB12040
  700 FS=S6/RB                                                              ASB12041
      WRITE(6,1265) RB,FS                                                   ASB12042
 1265 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,            ASB12043
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                              ASB12044
     2' LBS',/,/,/,/,27X,'A 4000 LB. STANDARD COAST GUARD ANCHOR WILL PROV  ASB12045
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                     ASB12046
      GOTO 1200                                                             ASB12047
  800 FS=S7/RB                                                              ASB12048
      WRITE(6,1275) RB,FS                                                   ASB12049
 1275 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,            ASB12050
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                              ASB12051
     2' LBS',/,/,/,/,27X,'A 5000 LB. STANDARD COAST GUARD ANCHOR WILL PROV  ASB12052
```

```
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                    ASB12053
      GOTO 1200                                                            ASB12054
  900 FS=S8/RB                                                             ASB12055
      WRITE(6,1285) RB,FS                                                  ASB12056
 1285 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,           ASB12057
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                             ASB12058
     2' LBS',/,/,/,/,27X,'A 6500 LB. STANDARD COAST GUARD ANCHOR WILL PROV ASB12059
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                    ASB12060
      GOTO 1200                                                            ASB12061
 1000 FS=S9/RB                                                             ASB12062
      WRITE(6,1295) RB,FS                                                  ASB12063
 1295 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,           ASB12064
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                             ASB12065
     2' LBS',/,/,/,/,27X,'A 8500 LB. STANDARD COAST GUARD ANCHOR WILL PROV ASB12066
     3IDE A FACTOR OF SAFTEY OF ',F4.1)                                    ASB12067
      GOTO 1200                                                            ASB12068
 1100 FS=S10/RB                                                            ASB12069
      WRITE(6,1305) RB,FS                                                  ASB12070
 1305 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,44X,           ASB12071
     1'MINIMUM REQUIRED ANCHOR SIZE IS ',F7.2,                             ASB12072
     2' LBS',/,/,/,/,27X,'A 12750 LB. STANDARD COAST GUARD ANCHOR WILL PRO ASB12073
     3VIDE A FACTOR OF SAFTEY OF ',F4.1)                                   ASB12074
 1200 CONTINUE                                                             ASB12075
      RETURN                                                               ASB12076
      END                                                                  ASB12077
```

APPENDIX B

User Manual for the Computer Model, ASB1

USERS MANUAL FOR THE COMPUTER MODEL, ASB1

Introduction

A program has been developed which computes the total force, resultant moment and if articulated, the list angle on a spar device being acted upon by wind, current and wave forces. Consisting of a main program, MAIN, and 19 internally called subroutines, this program written in Fortran IV has been run successfully on the University of Rhode Island's ITELAS 5 digital computer. Every effort has been made to make this program as general as possible. Consequently, a wide variety of input data as outlined below may be used. Because of the large number of arrays which may be used during computation, it is necessary to allocate 320k bytes of core to execute this program. Unfortunately, as a result of the wide range of possible input data as well as the iterative nature of the program, it is not possible to estimate the amount of time required to compile and execute this analytical model.

This program may be thought of as having two distinct phases; a control phase and a computational phase. Program MAIN acts in a control capacity, reading input data, checking its validity and calling the appropriate subroutines. During the computational procedure, program MAIN keeps track of the internal counters present in the program and ensures that the iterative technique used to determine the spar list angle converges. Once the appropriate force, moment and list angle information has been computed for a given case, program MAIN, checks to see if there are more cases and if so resets all counters to their initial value.

The computational phase of the program consists of the subroutines. All of the actual calculations take place in these subroutines, there being at least one subroutine for each of the major steps shown in the

flowchart (Figure II-3). These computational operations are repeated in a cyclical manner until the convergence criteria specified in the main program, MAIN, is satisfied.

Input Data

The English system of units (pounds-mass, feet, seconds) is assumed for all input data unless otherwise specified. Since most of the environmental and structural data available to users of this program is described using this system of units, it was chosen to make running this program as easy as possible. All of the input data is read by the main program, MAIN, where it is checked to ensure that each value is within its allowable range. Should an input value be specified outside of this range, a message to this effect is printed out and the program is terminated. Input data may be grouped into three catagories; general information, spar structural information, and force information and should be read into the program in the following order. Unless otherwise specified, an F10.0 format is assumed for all input variables.

Program: MAIN

Input Variables

General Information

NCASE — Number of cases contained in the input data set (Integer *3)

IWAT — Water type. This value is used to define the fluid density and viscosity. It should be set equal to 1 if the buoy is to be located in salt water or 0 if this is not the case. (Integer * 1)

DEPTH — Still water depth.

Spar Structural Information

SPL,SPW.SPD — Spar length; spar width; spar depth.

SM,SMD,SWT — Spar material (Alpha-numeric * 10); spar material density; spar wall thickness. If the spar is a solid structure, then the spar wall thickness value should be set equal to 0.00.

IVANE — Orienting vane flag. This value should be set equal to 1 if an orienting vane is present, otherwise this value should be set equal to 0 and the next three vane information data cards omitted. (Integer * 1).

VL,VHT,VT — Vane length; vane height; vane thickness.

VM,VMD — Vane material (Alpha-numeric * 10); vane material density.

VHGT — Vane height. This is the height from the bottom of the spar to the bottom edge of the orienting vane.

IART — Articulation flag. If the buoy is articulated about its base then this value should be set equal to 0. If this value is not equal to 1, then it is assumed that the spar acts as a pile structure which is aligned perpendicular to the bottom and, therefore, no list angles or righting moments are computed. (Integer * 1).

ANCHX,ANCHY — Coordinates of the anchor attachment point relative to the center of the bottom face of the spar.

Force Information

NWDP — Number of wind data points. This value establishes the number of elemental areas into which that portion of the spar which is above the still water surface is divided.

Because of dimension limitations on the wind arrays, this value should always be less than 100. If this value is set equal to 0, then the next wind information data card must be omitted. (Integer *3)

WSPD,WDIR — Wind speed (in miles per hour); wind direction (in degrees magnetic)

WLEEV,FETCH — elevation at which the wind speed was measured; fetch length.

NCOP — Number of current data points. This value establishes the number of elemental areas into which the submerged portion of the spar is divided for the purpose of computing current velocity information. This value should not exceed 500 because of dimension limitations on the current arrays. If this value is set equal to 0, it is assumed that no current forces are present and thus the next three current information data cards must be omitted. (Integer * 3)

ICUR — Uniform current flag. This value determines whether a single set of variables or an array of current information are the next input avariables. This value indicates whether the current velocity profile is uniform or not. If this value is set to 1 then the following data card should contain the variables UCVEL and UCDIR. If this value is 0 then the subsequent data cards should contain the current velocity profile VEL, DIR, DEP. (Integer * 1)

UCVEL,UCDIR — Uniform current velocity; uniform current direction. These array elements are read in only when the ICUR value has been set equal to 1.

VEL,DIR,DEP Current velocity; current direction; current depth. These array values are read in when the ICUR variable has been set equal to a value other than 1. Having a length equal to NCDP + 1, each row of this array contains the current speed and direction at an associated depth. Beginning with a water depth of 0.00, this current profile information must be supplied at equally spaced depth increments.

NWADP Number of wave data points. This value establishes the number of elemental areas into which the submerged portion of the spar (as measured from the still water surface) is divided for the purpose of computing wave particle velocity and acceleration information. Because of dimension limitations on the wave arrays, this value cannot exceed 500. Further, if both wave and current forces are present in an analysis, this value must be less than or equal to NCDP. If the NWADP value specified is non-zero and less than NCDP then it is increased to equal NCDP and a message to the effect is printed. If NWADP is set to 0, no wave forces are present and the next four wave data cards must be omitted. (Integer * 1)

IWAVE Wave flag. If the significant and average wave heights and wave periods are to be supplied, this value should be set to 1. If this value is other than 1 then this wave information is internally calculated in subroutine WAVSMB and, therefore, the next wave data card should be omitted. (Integer * 1)

TSIG,TAVG, Significant wave period; average wave period;

HGTSIG,HGTAVG significant wave height; average wave height. These values are read in only when the IWAVE parameter is equal to 1.

ITIME Time step increment. This value establisnes the number of time increments into which the average wave period is divided. The total force on the spar and its resulting list angle is computed at each of these time steps. (Integer * 3)

ITHERY Wave theory flag. This value should be set equal to 1 if linear, (Airy) wave theory is to be used to compute the wave particle motions and surface profile. A value of 2 is used to specify that Stokes second order wave theory is to be used to compute these wave parameters. (Integer * 1)

ION Integer output number. This value should be set equal to 1 if a listing of all of the intermediate calculations used to compute the resultant list angle is desired. If this value is other than 1, no such listing will be produced. (Integer * 1)

Additional General Information

NEWPD New physical data. This value is only read in when the number of cases in the input data set is greater than 1. If new general and spar structural information is to be forthcoming then this value should be set to 1, otherwise it is assumed that only the force information is to be varied and the value read in is assigned to the variable NWOP.

THE SUBROUTINES

The subroutines described below are listed in the order in which they are called by the program, MAIN. The first four subroutines are called only once by the main program because the calculations involved are independent of the spar's list angles.

Subroutine WEIGHT

The WEIGHT subroutine computes the weight of the entire spar device in both air and water. If the spar has been previously identified by the I-T parameter as being articulated then its total buoyancy is determined. Based upon this information, a check is then made to ensure that the specified spar design acting as a free body in the absence of any environmental forces will float. Should the dimensions of the spar have been specified so that a particular design will not float, a message to this effect is printed and the program terminated.

Subroutine WNDSPD

The WNDSPD subroutine computes the wind speed profile from the wind velocity input data based upon the Prandtl-von Karman universal distribution law.

Subroutine WAVSMB

The significant wave height and significant wave period of a wave is computed in subroutine WAVSMB using the S.M.B. method. Assuming that the wave height and the square of the wave period are both Rayleigh distributed, average values for these two parameters are also determined. (Ippen, 1965). These average values are subsequently used in the wave force calculations.

Subroutine WAVE

Subroutine WAVE is called by the program, MAIN, to compute basic information about the waves acting on the spar including the wavelength, wave celerity, wave frequency and the wave number. A wave amplitude value based upon the previously selected wave theory is also computed.

Subroutine AREAS

In this analysis, the total area exposed to wind forces is determined by the distance from mean sea level to the top of the spar; the total current area is determined by the distance from mean sea level to the bottom of the spar and the total area exposed to wave particle forces is determined by the distance from the free surface to the bottom of the spar. These distances, which are computed in subroutine AREAS, vary as a function of the spar's list angle. Further, since the distribution of the driving force velocities and accelerations may have large spatial variations in the vertical, subroutine AREAS divided these three areas into many equal elemental areas. The exact number of elemental areas into which an area exposed to a driving force is divided is equal to one less than the number of data points assigned to that force (i.e., one less than NWDP, NCDPAND, NWADP).

Subroutine CBEAR

Because the environmental forces in this model are defined with respect to a fixed reference point (i.e., magnetic north), it is necessary to define the orientation of the spar in relationship to this point in order that the relative forces acting on the spar be established. Subroutine CBEAR is called to compute this orientation when the buoy configuration under study has a splitter plate or other vane. This

subroutine assumes that a buoy's orientation is defined by the current direction at the centroid of its vane.

The Velocity Subroutines

Once the orientation of the spar has been established with respect to magnetic north, the driving force velocities normal to the spar in the X and Y directions are determined.

Subroutine RWVEL

Subroutine RWVEL calculates the wind velocities normal to the spar in the X and Y directions. In this subroutine, velocities are computed at the center of each elemental wind area.

Subroutine RCVEL

Current velocities normal to the spar in the X and Y directions are computed in subroutine RCVEL. These velocities are computed at the top and bottom of each elemental current area and then averaged linearly to determine the velocity at the center of each area.

Subroutine RWAVA

In subrouine RWAVA the water particle velocities and accelerations normal to the spar in the X and Y directions are computed. These values are computed at the top and bottom of each elemental wave particle area and then averaged linearly to determine the velocity and acceleration terms at the center of each area.

Subroutine WPV

In order to properly compute the total force due to current and waves acting on the spar, it is necessary to compute the total water particle velocity by summing these individual components at each depth of interest.

> "When current is present, fluid forces may still be evaluated according to Morrison's formula (Myers, 1969). This is achieved by considering fluid particle velocity as the vector sum current velocity and wave induced particle velocity. Since the drag force is non-linear, it cannot be regarded as a simple superposition of current and wave drag forces." (Wu and Tung, 1975)

Subroutine WPV combines these current and wave particle velocities to determine the water particle velocity and associated water particle area at each depth of interest.

The Drag Coefficient Subroutines

Subroutine DRAGC

Subroutine DRAGC is called by program MAIN when the spar being studied has a cylindrical cross-section (i.e., SPW = SPD). In this subroutine, drag coefficients are computed at each elemental area from Reynolds number determinations according to the U.S. Army Corps of Engineers Recommended Design Curve. (U.S. Army Corps of Engineers, 1973).

Subroutine DRAGX

If the spar under study does not have a cylindrical cross-section then drag coefficients for driving force velocities in the X-direction to each elemental area are calculated in subroutine DRAGX based upon empirically derived relationships. (Hoerner, 1965)

Subroutine DRAGY

No empirical relationship describing the drag coefficient on an elliptical body whose major axis was normal to the flow could be found in the literature. Consequently, this subroutine assumes that such a shape may be considered a flat plate and, therefore, assigns a drag coefficient value of 2.0 to driving force components acting in this direction.

Subroutine FORCE

The wind and water particle normal forces on each of these elemental areas is computed in subroutine FORCE using the Morison equation and velocity, acceleration, area and drag coefficient information from previous subroutines. Subsequently, the total wind and water particle normal force on the spar is determined by summing each set of these elemental forces.

Subroutine OTMOM

Subroutine OTMOM computes the total wind and water particle overturning moments acting on the spar in the X and Y directions. These values are subsequently added together so that the total overturning in each of these directions is known.

Subroutine RMOM

This subroutine calculates the total righting moment acting on a spar in the X and Y directions based upon buoyancy considerations and the total spar weight.

The Intermediate Output Subroutines

For the purpose of checking the final output or the computations performed in a subroutine, the intermediate output subroutines when called by program MAIN print the results of all significant calculations used to determine the total force, resulting moment and list of angle of a spar.

Subroutine INOUT 1

This subroutine prints the results of all the significant calculations performed in the following subroutines: AREAS, CBEAR, RWVEL, RCVEL, RWAVA, DRAGC, DRAGX, and DRAGY.

Subroutine INOUT 2

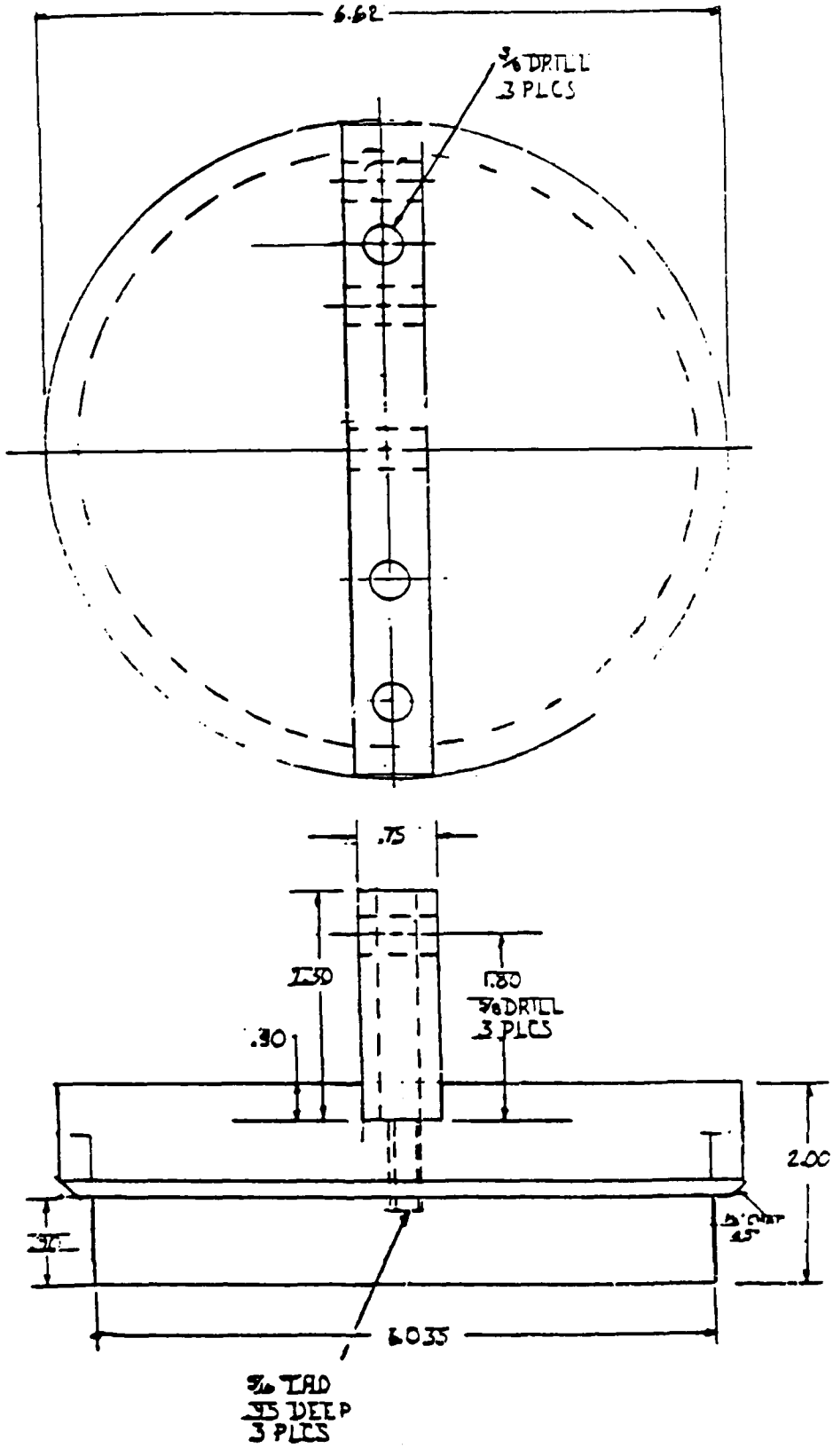
This subroutine prints the results of all the significant calculations performed in the following subroutines: FORCE, OTMOM, AND RMOM.

Subroutine ANCHOR

Subroutine ANCHOR determines the maximum buoyant force acting on the spar during one wave period. Subsequently, the minimum standardized anchor size needed to resist this buoyant force in determined and the factor of safety associated with this anchor selection is computed.

APPENDIX C

Design Drawings of the Field Test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3 PLCS
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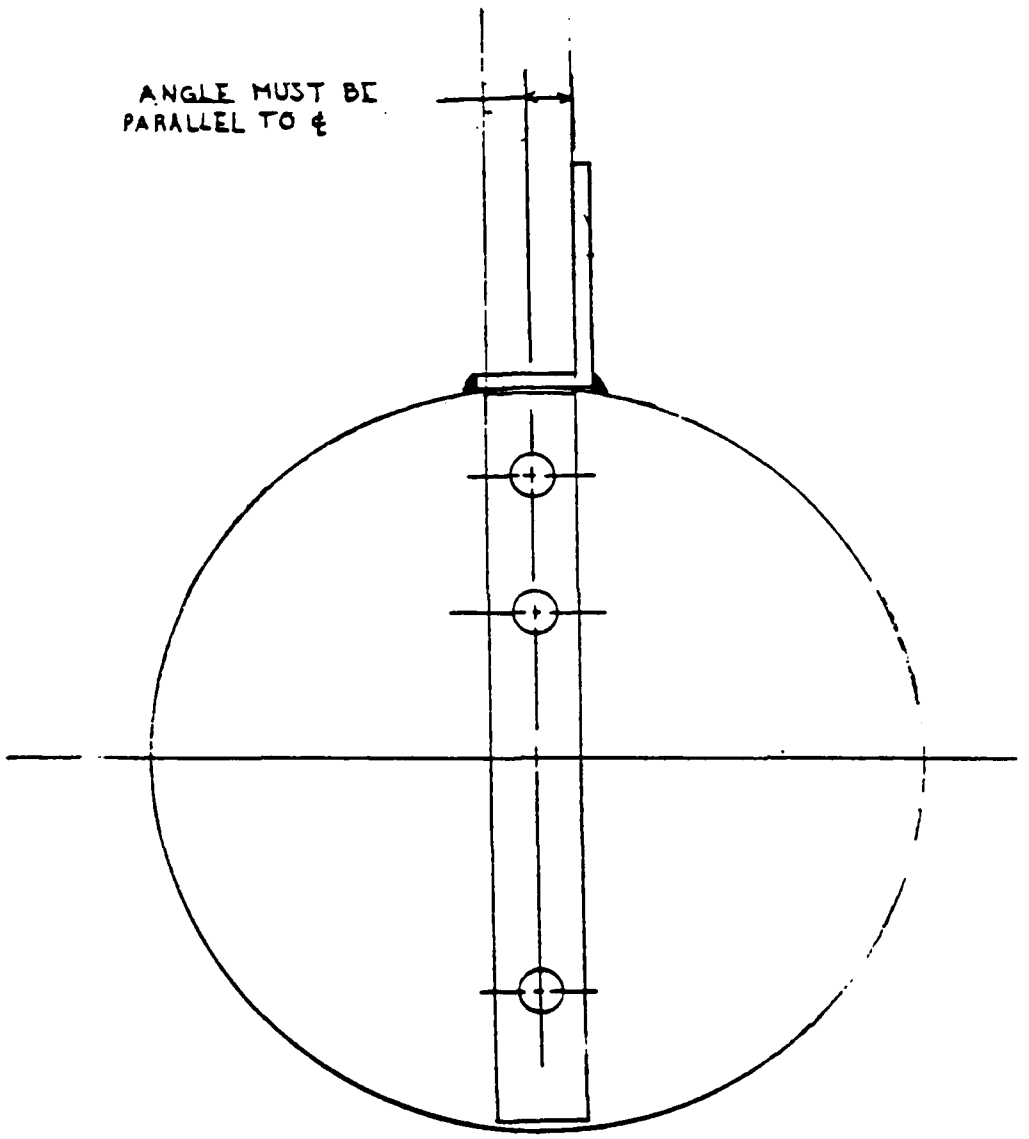
.30
2.00
6.035
⅜ TAP
.35 DEEP
3 PLCS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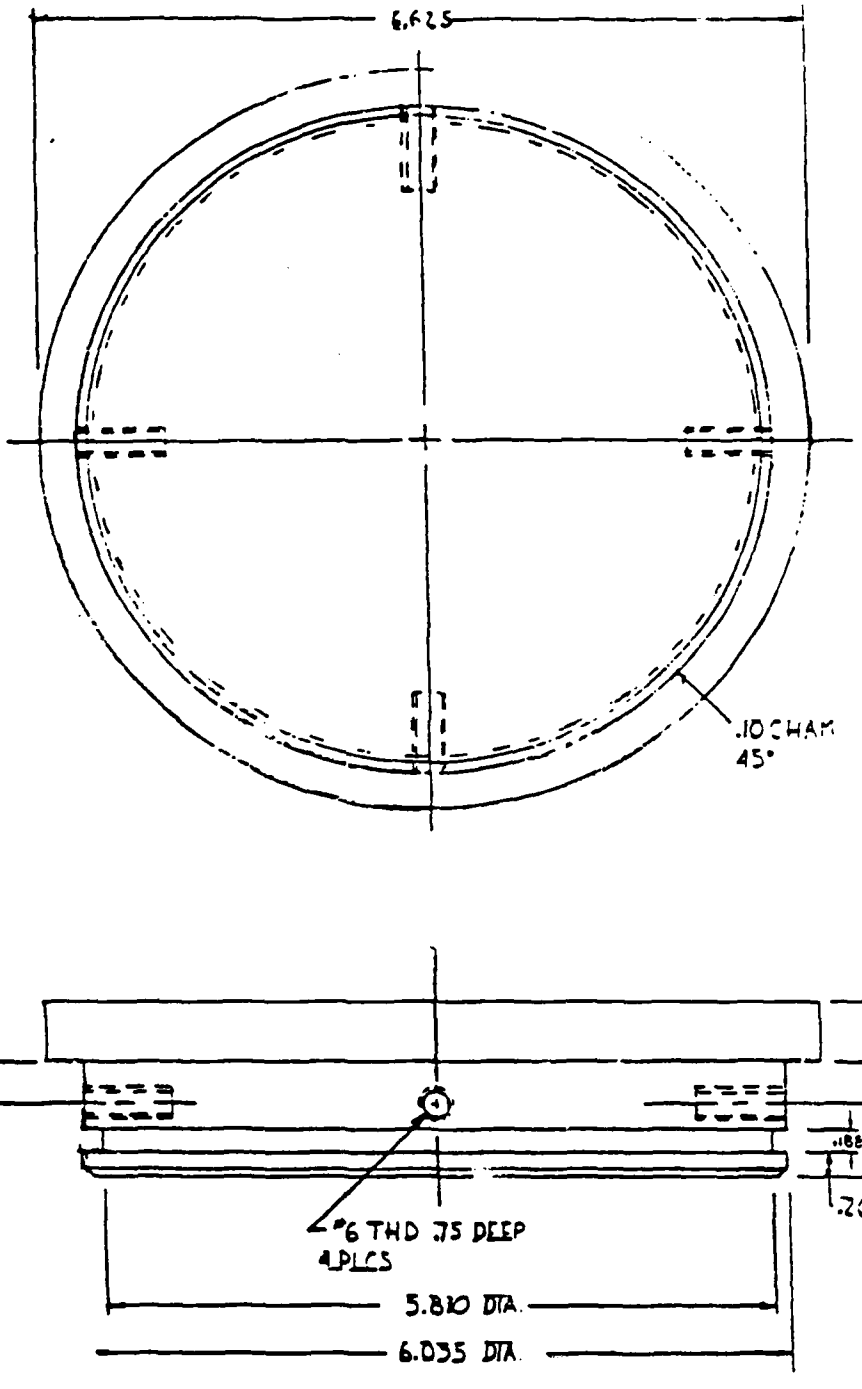
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.10 CHAM
45°
.35
1.55
1.00
.188
.20
#6 THD .75 DEEP
4 PLCS
5.810 DIA.
6.035 DIA.


DAT
ILM